CONCRETE CORES FROM DRY DOCK NO. 2 CHARLESTON NAVAL SHIPYARD, S. C.

by

Alan D. Buck

Katharine Mather

June 1969

Sponsored by

Southeast Division
Bureau of Yards and Docks
U. S. Navy

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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Foreword

The investigation reported herein was first proposed in a letter
dated 19 November 1965 from Mr. Herman G. Protze, Materials Technologist,
Wellesley, Mass., to Mrs. Katharine Mather, Chief, Petrography and X-Ray
Section, Engineering Sciences Branch, Concrete Division, U. S. Army Engi-
neer Waterways Experiment Station (WES). Mr. Protze, hired by Fay, Spofford
and Thorndike, Inc., Engineers, Boston, Mass., as a consultant, stated in
his letter that he was forwarding concrete samples from Dry Dock No. 2,
Charleston Naval Shipyard, S. C., for examination. By letter dated 3 Decem-
ber 1965 to the Director, WES, the Southeast Division, Bureau of Yards and
Docks (BuDocks), authorized the performance of the examinations proposed by
Mr. Protze. MIPR R-66-5 was furnished to cover cost of the work. Progress
reports were furnished under dates of 14 January and 4 February 1966. They
are included herein as Appendixes A and B. These progress reports were also
included as Inclosures E and F to "Report on the Present Condition of the
Concrete in Dry Dock No. 2," dated February 1966, submitted to the Director,
Southeast Division, BuDocks, by Fay, Spofford and Thorndike, Inc.

The data developed were reviewed in conversations with Mr. Protze,
Mr. Royal C. Flanders of Fay, Spofford and Thorndike, Inc., and representa-
tives of the Southeast Division, BuDocks. By an amendment dated 1 June 1966
to MIPR R-66-5 additional funds were provided to cover the preparation of a
report.

The investigation was conducted at the WES Concrete Division during
the period December 1965-June 1966 under the supervision of Messrs. Bryant
Mather and R. V. Tye by Mr. Alan D. Buck and Mrs. Mather. Mr. Buck and
Mrs. Mather prepared this report.

Directors of the WES during the conduct of this study and the prepa-
ration of this report were COL John R. Oswalt, Jr., CE, and COL Levi A.
Brown, CE. Technical Directors were Messrs. J. B. Tiffany and F. R. Brown.

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Contents

Conversion Factors, British to Metric Units of Measurement

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters

Summary

Eight concrete cores from Dry Dock No. 2, Charleston Naval Shipyard, S. C., were examined to determine whether evidence could be found that alkali-silica reaction had occurred in the concrete and whether, if this reaction had occurred, it was still continuing.

The appearance of some of the concrete and of the associated white porcelaneous secondary reaction product (gel) indicated alkali-silica reaction had occurred. However, the quartz aggregate used in this concrete is not among types of material usually considered to be reactive. In addition, the gel material was definitely more crystalline than alkali-silica gel has usually been found to be.

Various tests and examinations were made of the gel, the aggregate, the cement paste, and the concrete. None of the data suggested that the aggregate would be diagnosed as reactive by normal criteria. It appeared that only one source of aggregate had been used in the concrete.

Chemical analysis of a 0.4-g sample of gel from the reacted concrete showed it to consist largely of water, silica (SiO_2), lime (CaO), and potassa (K_2O); the last amounted to 19 percent. The approximate chemical formula of this material, $CaO.K_2.5SiO_2.5H_2O$, is reasonable as a generalized formula for impure alkali-silica gel; the microscopical examinations showed that this gel consisted of at least three different crystalline phases. One of these included amorphous material that is probably alkali silica gel.

After consideration of all of the available data it is concluded that alkali-silica reaction has occurred and that the effects of this reaction have essentially terminated.

Since the alkali portion of the gel was high in K_2O and low in Na_2O, it is believed that the source of this alkali was the cement rather than the sea water to which the concrete was exposed.

The rather unusual environment of the dry dock with its unequal periods of wetting and drying of the concrete probably resulted in moving concentration fronts or local concentrations of alkali from the cement which together with other environmental factors caused the reaction to occur.

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Not all of the concrete exhibited alkali-silica reaction. This may signify that two cements were used and reaction was confined to the concrete made with the one of higher alkali content, or it may be due to an undetermined environmental factor. It seems more probable that cements of different alkali contents were involved.

Progress reports 1 and 2 are included as Appendixes A and B, and WES Technical Memorandum No. 6-224 is included as Appendix C.

CONDITION OF CONCRETE IN DRY DOCK NO. 2,
CHARLESTON NAVAL SHIPYARD, S. C.

Introduction

1. A laboratory investigation of concrete cores from Dry Dock No. 2, Charleston Naval Shipyard, Charleston, S. C., was undertaken by the U. S. Army Engineer Waterways Experiment Station (WES) to provide answers to the two following questions. Has a deleterious chemical reaction occurred in some or all of the concrete? If a deleterious chemical reaction has occurred, do its physical effects continue to produce expansion and cracking in the structure today? It is assumed that a continuing chemical reaction that had no undesirable physical consequences on the volume stability or strength of the concrete would be of no concern because it would have no practical consequences.

2. The answers to these questions were needed to assist in deciding whether or not the existing concrete walls can be incorporated in proposed modifications to the dry dock. Dry Dock No. 2 was constructed in 1942 by the McDougal Construction Co.

Samples

3. Two 4-in.-diameter concrete cores from Dry Dock No. 2 were received on 29 November 1965. Six more 4-in.-diameter concrete cores were received on 16 December 1965. All were provided by Mr. Herman G. Protze.* The locations in the structure from which the cores were taken are shown in plate 1.

4. Identifying data for the samples are shown on the following page:

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* Mr. Herman G. Protze, Materials Technologist, 41 Martin Rd., Wellesley, Mass., Consultant for Fay, Spofford and Thorndike, Inc., Engineers, Boston, Mass.

CD Serial No. BYD-1	Field No.*	Date Rec'd 1965	Depth, Back of Dock Face, in.	Condition
CON-3	1S-6	16 Dec	41-3/4 to 49	Cracked; reaction product
CON-4	2S-4	16 Dec	39-1/2 to 53-3/4	Cracked; reaction product
CON-5	3S-3	16 Dec	28 to 38	No visible cracks or deposits
CON-1	4S-4C	29 Nov	43 to 52	No visible cracks or deposits
CON-6	6S-1	16 Dec	0 to 12	Cracked; reaction product
CON-7	4N-5	16 Dec	32-1/4 to 44-3/4	No visible cracks or deposits
CON-8	6N-1	16 Dec	0 to 15	Cracked; reaction products
CON-2	6N-3	29 Nov	27-1/4 to 39-1/2	Cracked; reaction products

* S in the field number refers to the south and N to the north wall of the dry dock.

All cores were taken from elevations -10.6 to -17.9** except core 3N which was taken at an elevation of +0.7 and 3S which was taken at an elevation of +0.8. Unless core 3N shows evidence of reaction, the cores that show reaction represent the lower third only of the wall, so that there is no representation of reacted concrete in the upper two-thirds of the wall that has been examined here. The lateral distribution of the cores along each wall indicates reacted concrete in both walls near the inboard end (cores 6N and 6S) and toward the outboard end (1S and 2S, and 2N as examined by Dr. Levi S. Brown†) with regions of unaffected concrete midway on each side (4N, 4S, and 3S, and 5S as examined by Dr. Brown).

5. Eleven soil samples from two boreholes located about 60 ft from the inboard end of the dry dock were received on 14 December 1965 from Fay, Spofford and Thorndike. These soil samples were believed to be representative of soils adjacent to the dry dock. The samples are identified as follows:

** All elevations (el) cited herein are in feet referred to mean sea level.
† Dr. Levi S. Brown, Consulting Engineer, Portland Cement and Concrete, 570 Northwest Highway, Des Plaines, Ill., acted as a consultant for Fay, Spofford and Thorndike.

		Field Identification		
CD Serial No. BYD-1	Borehole No.	Sample No.	Sample Taken at Depth, ft	Description
SS-1	9	1	5	Blue clayey sand
SS-2	9	2	10	Gray clay
SS-3	9	5	25	Marl
SS-4	9	6	30	Marl
SS-5	9	8	40	Marl
SS-6	10	1	5	Gray fine silty sand
SS-7	10	2	10	Soft blue clay
SS-8	10	3	15	Brown medium sand
SS-9	10	4	20	Marl
SS-10	10	5	25	Marl
SS-11	10	6	30	Marl

Test Procedure

Visual and stereo-microscopic examinations

6. The cores were examined with the naked eye and with a stereo-microscope when they were received. The first two cores received (4S-4C and 6N-3) were sawed longitudinally, and these sawed surfaces were also examined. One-half of each of these two cores was stored in water for several days with its sawed surface above the water. These surfaces were examined at intervals for the development of or enlargement of the gel reaction product during this storage. Fragments of the gel were placed in dilute hydrochloric acid and observed for possible reactions.

7. Since all of the cores had been drilled horizontally, various features were studied to determine the orientations of the cores. Once these were known the orientation of the cracks in the structure was known from the cracks present in the cores.

Photographs

8. Six photographs were taken of four of the five cores that showed cracking and deposits of gel (see figs. 1-4).

Examinations by polarizing microscope

9. Thin sections were prepared from cores 4S-4C, 6N-3, 1S-6, and 2S-4 for examination with a polarizing microscope.

10. Samples of deposits in voids and of the gel present in the
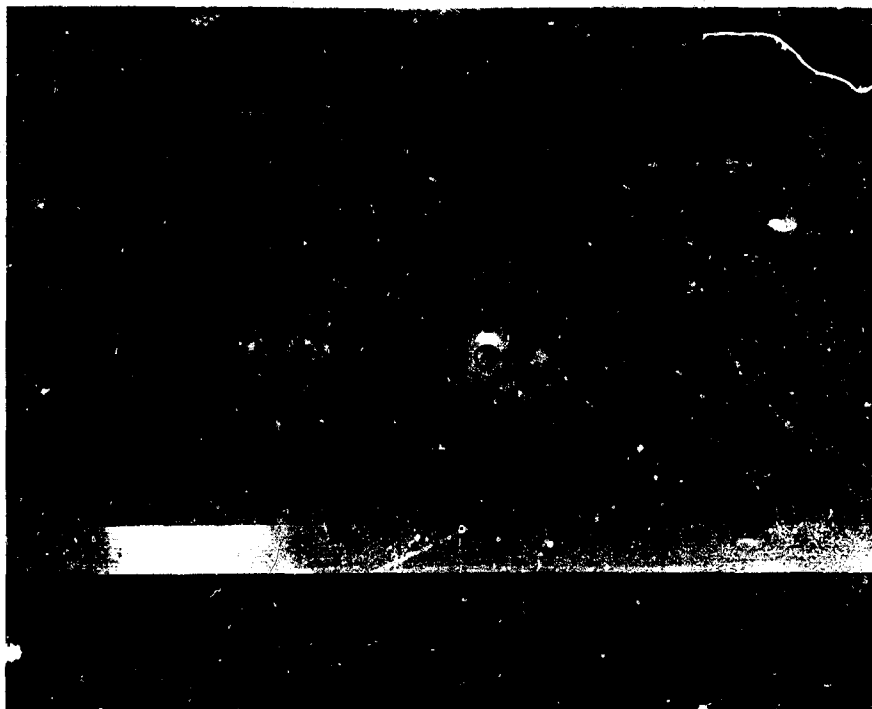
Fig. 1. Core 1S-6, depth 41-3/4 to 49 in. Holes visible
in the aggregate particles of this core and the cores in
subsequent photographs were made by a small-diameter core
barrel to obtain samples of coarse aggregate

concrete were selected by handpicking under a stereomicroscope. Powder
immersion mounts of the reaction products in oils of different refractive
indices were studied with a polarizing microscope to determine optical
properties.

X-ray examinations

    11. Secondary reaction product (gel).

        a. A sample of the white porcelaneous gel, from a 1/4-in. void,
was ground in water to make a slurry which was allowed to
dry on a 1/4-in.-wide glass slide. X-ray diffraction pat-
terns of the dry film were made.

        b. A composite sample of gel, handpicked for chemical analysis,
was also examined by X-ray methods; X-ray diffraction and
emission patterns were made of a tightly packed powder sur-
face. An X-ray pattern was also made of this material after
it had undergone differential thermal analysis (DTA) up to
1000 C. Another portion of this material was ground in al-
cohol and the slurry was placed on an aluminum surface and
dried at 450 C; the dried film was X-rayed.

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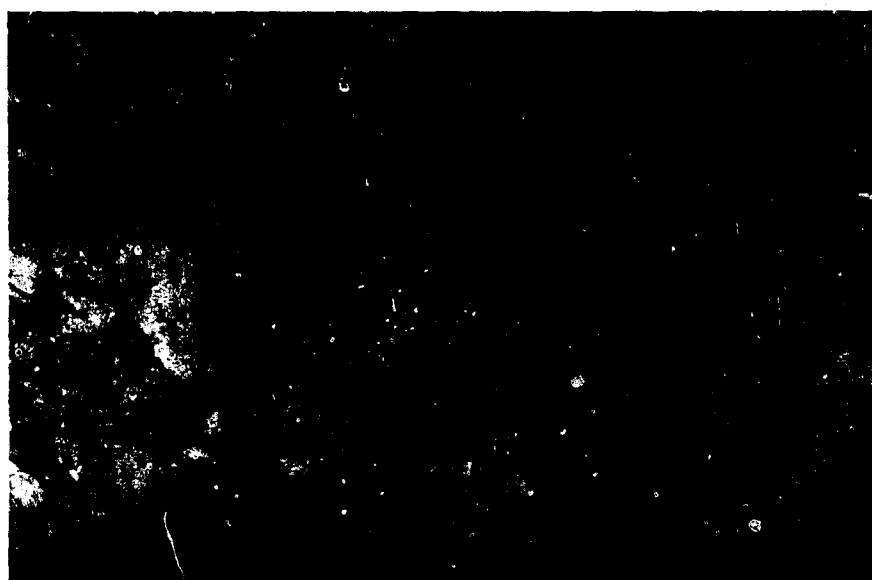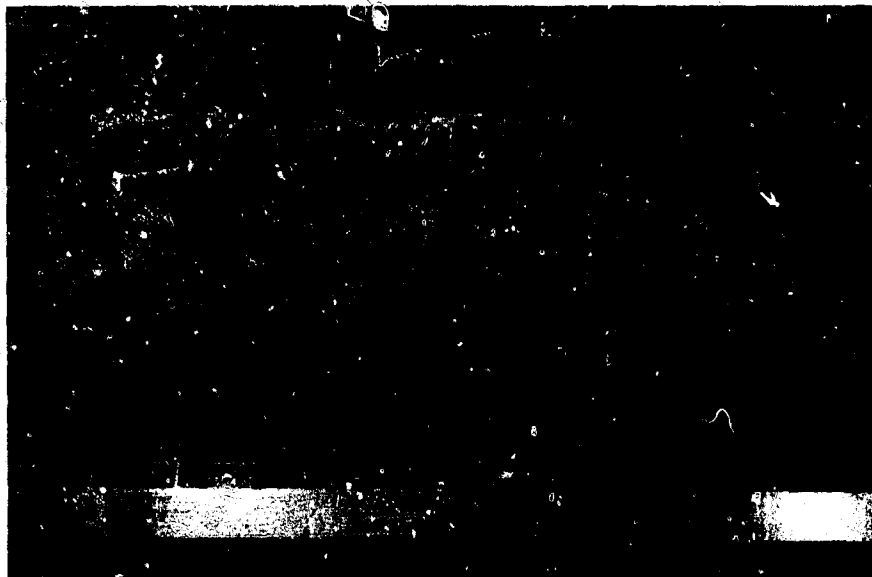
Fig. 2. Core 2S-4, depth 39-1/2 to 53-3/4 in. Top photograph shows general appearance of core; bottom photograph gives closer view of old cracks. The circled aggregate particle reacted after the core was drilled. The rough appearance of the particle was produced by reaction products hardening around some of the sawdust in which the core was packed for shipment. The white spots above, below, and at the right tip of the reacted particle are cavities filled with alkali-silica reaction product
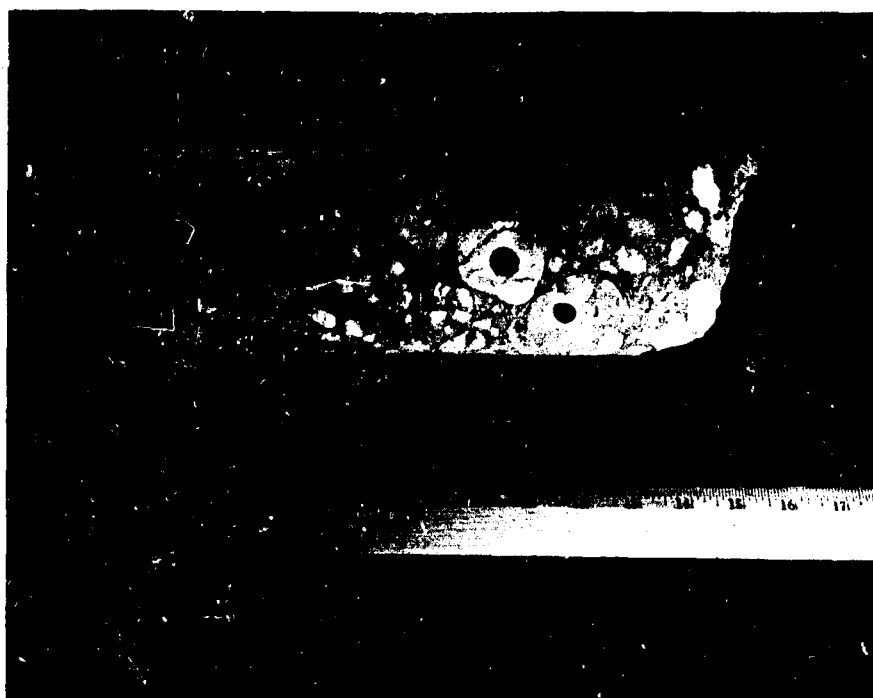
Fig. 3. Core SS-3, depth 28 to 38 in.

Fig. 4. Core 6N-1, depth 0 to 15 in.

c. Some of the reaction product, identified in this study as
layered tan material, was X-rayed after drying from an al-
cohol slurry.

12. Paste samples. Material representing cement paste from reacted
concrete (cores 2S-4 and 6S-1) and unreacted concrete (core 3S-3) was ob-
tained from freshly exposed broken surfaces to minimize carbonation of the
cement paste. All possible precautions were taken to ensure that the sam-
ples were as free as possible from aggregate contamination. The samples
were ground and X-rayed as tightly packed powders in a nitrogen atmosphere
to prevent carbonation of the paste.

13. Coarse aggregate. Fragments from five coarse aggregate particles
in core 6N-3 were obtained and then ground and X-rayed as tightly packed
powders. One piece of fine aggregate was examined in the same way.

14. Soils. An X-ray pattern was made of each of the 11 samples in
its as-received condition. Each sample was tightly packed to create the
best possible surface; a saturated atmosphere was maintained while making
the patterns. In addition, sample 8 from the 40-ft depth of borehole 9 and

sample 6 from the 30-ft depth of borehole 10 were examined as follows. A water slurry of each sample was allowed to dry on a glass slide. This surface was X-rayed air-dry and after saturation with glycerol.

15. <u>X-ray conditions.</u> All of the diffraction patterns were made with an X-ray diffractometer using nickel-filtered copper radiation. The emission pattern was made on a similar unit arranged for emission spectroscopy; the examination was made in a helium atmosphere with a PET analyzing crystal and with chromium radiation.

Chemical analysis

16. <u>Gel.</u> The sample of gel gathered for chemical analysis amounted to 0.4 g of material after drying to constant weight at 450 C. It was analyzed for major oxides by wet chemical methods except that the amounts of K_2O and Na_2O were determined by the use of a flame spectrophotometer.

17. <u>Quick chemical test of aggregate.</u> A sample of coarse aggregate from the reacted concrete (cores 6N-1, 1S-6, 2S-4, and 6S-1) and from the unreacted concrete (cores 3S-3 and 4N-5) was prepared as follows. Small cores (0.35 in. in diameter) were taken from several coarse aggregate particles exposed on the large core surfaces; all adhering mortar was trimmed away with a diamond saw. The resulting aggregate samples were crushed and sized to pass the No. 50 sieve and be retained on the No. 100 sieve. All adhering fines were removed by washing. The amount of each sample remaining was about 32 and 30 g. This material was then tested for potential reactivity by immersing in alkali solutions in accordance with CRD-C 128-62[1] except that only a single determination was made because of the small amount of material available for test.

Differential thermal analysis (DTA)

18. A sample of gel was examined by DTA. This sample was identical with that used for chemical analysis and for some of the X-ray examinations.

Field data

19. The records[2] of movement in and of the dry dock as indicated by reference metal plugs were studied and tabulated.

Progress reports

20. Progress Reports 1 and 2 were prepared during the study. They are included herein as Appendixes A and B, respectively.

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Results

21. The results are presented below as they were obtained from tests on the concrete cores, the coarse aggregate, the gel, and the soil samples, respectively.

Cores

22. Orientation studies of the cores revealed that in all of the cracked cores, the cracks dipped downward into the basin of the dry dock.

23. Five of the cores (6N-3, 6N-1, 1S-6, 2S-4, and 6S-1) showed evidence of deleterious reaction. The evidence was the old cracks in the cores and the white porcelaneous gel that coated the crack surfaces. This gel also was found in voids and lining aggregate sockets in the cores. Core 6N-3 probably exhibited the most signs of reaction. Three of the cores (4S-4C, 3S-3, and 4N-5) exhibited no signs of deleterious chemical reaction; they were not cracked nor were they observed to contain any gel. Aside from the evidence of reaction in five of the eight cores, there were no observed differences in the concrete.

24. No brown stalactites were observed in or on any of the eight cores that were examined. (Mr. Protze's letter of 19 November 1965 mentioned that brown stalactites were common on exposed concrete surfaces at the seams in the dry dock.)

25. In fig. 2 the white porcelaneous gel can be seen on the surface of core 2S-4. The small drill holes that are visible in figs. 1-4 in many of the coarse aggregate particles on the core surfaces represent the cores of coarse aggregate removed for the quick chemical test.

Concrete

26. Examination of thin sections of reacted concrete from cores 6N-3, 2S-4, and 1S-6 and of thin sections of nonreacted concrete from core 4S-4C indicated:

  a. The coarse aggregate was quartzite. Some of the particles were strained. There may have been some vein quartz pebbles.

  b. The fine aggregate was a natural sand composed of quartzite, quartz, and feldspar grains.

  c. None of the aggregate particles showed definite signs of having reacted.

<u>d</u>. The appearance of the residual unhydrated cement in the cement paste suggested that the original cement was high in aluminoferrite content. The cement paste was not carbonated and there was abundant calcium hydroxide, although calcium hydroxide was depleted near some reacted coarse aggregate particles.

<u>e</u>. The gel was very common in the thin sections of reacted concrete; it was not recognized in the thin sections of the nonreacted core.

<u>f</u>. Cracking was very apparent in the thin sections of the reacted concrete; cracking was not found in the thin sections of the nonreacted concrete.

<u>g</u>. There was no apparent difference in the aggregate or cement used in the reacted and nonreacted concretes.

27. X-ray examination was made of the paste from three cores: (a) 2S-4 reacted concrete, (b) 6S-1 reacted concrete, and (c) 3S-3 nonreacted concrete. This examination indicated that about the same amounts of normal hydration products were present in each core. No peaks attributable to the gel were detected in any of these patterns. There did seem to be a decrease in the amount of calcium hydroxide present as the amount of visible reaction increased in the concrete.

28. Calcium sulfoaluminate was present as clusters of tiny white rosettes of needles partially filling some voids in the concrete. The amount and type of occurrence appeared to be normal.

29. The data in tables 1 and 2, which concern vertical movements of the dry dock since 1945 and horizontal movements since 1953, suggest that the amount of movement became less with increasing age of the structure.

<u>Coarse aggregate</u>

30. The results of the quick chemical test, shown in fig. 5, do not indicate a potentially reactive aggregate. These results are discussed in Progress Report 2 (Appendix B).

31. As mentioned earlier, the coarse aggregate in all of the cores is quartzite with perhaps some vein quartz particles. The X-ray examination of several quartzite particles from the reacted concrete of core 6N-3 indicated that all of the rock was quartz. There were no other minerals present.

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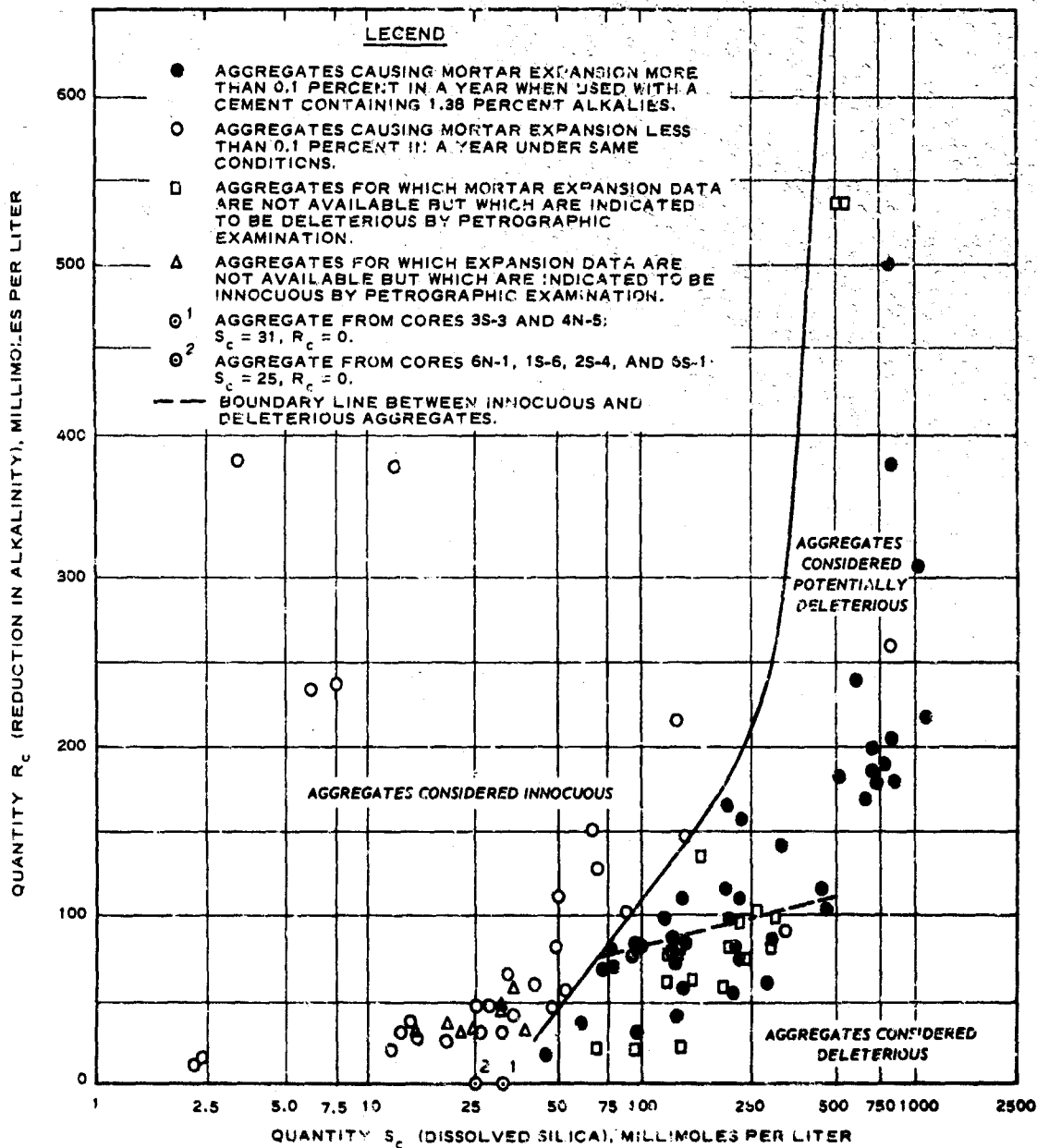
Fig. 5. Results of quick chemical test (CRD-C 128, ASTM C 289)[1] on coarse aggregate from six concrete cores from Dry Dock No. 2

Secondary reaction product (gel)

32. There were at least three distinctly different phases present in the white porcelaneous material that was found in voids, in aggregate sockets, and on old crack surfaces of the reacted concrete. Most of the laboratory tests were made on this multiphase gel. As stated in Progress

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Report 2 (Appendix B), the gel gave every indication of being alkali-silica gel. The fact that it was more crystalline than the usual gel of similar appearance is now known to be due to the fact that several phases, some crystalline ones, were present.

33. Some of the properties determined by test of the multiphase gel are recorded below:

a. When part of core 6N-3 was stored in water for several days, the gel exposed on a sawed surface of the core swelled because of imbibition of water.

b. When placed in dilute hydrochloric acid, the gel dissolved with very little effervescence and left a soft, transparent, probably siliceous, residue.

c. Quartz grains and carbonate grains were usually present as minor contaminations in the gel samples.

d. The chemical analysis of a 0.4-g sample of this gel is shown in table 3. The data indicate that the generalized formula for this sample is

$$CaO.K_2O.5SiO_2.5H_2O$$
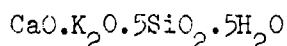
This is certainly not the actual formula since the sample contained several phases, but it is probably approximately correct and is satisfactory for an alkali-silica gel. X-ray emission examination of some of this same material indicated that it was composed largely of silica, potassium, and calcium. Since the X-ray method does not detect the hydrogen or oxygen present in the water, these results were in good agreement with those of the chemical analysis.

e. X-ray diffraction and DTA examinations were made of some of the same material that was used for chemical analysis. No successful identifications were made. The probable reasons for this are discussed later.

34. The results of the examination of the separate phases of the gel are discussed below:

a. White porcelaneous gel from a 1/4-in. void. The optical and X-ray data showed that this material consisted of at least two unidentified phases plus minor amounts of calcium carbonate. One of the unidentified phases was the tan layered material which is discussed below. The material typical of the gel in this 1/4-in. void is crystalline. It is transparent in plane-polarized light and has a salt

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and pepper type of texture under crossed nicols. Many cherts have a similar texture. The average refractive index of this material is about 1.494.

b. **Tan layered material.** This material is hard, brittle, and has a layered structure like that common to opal. The material was found coating one void. An X-ray pattern was made of this material which is believed to be one crystalline phase. The X-ray data indicate that this phase was also present in the gel from the 1/4-in. void and in the composite gel sample used for chemical analysis. If the fibers in this material are uniaxial then they are length slow positive crystals with positive elongation. They have low or moderate birefringence and parallel extinction. The refractive index lies between 1.510 and 1.544.

c. **Alkali-silica gel.** This was one of the three phases present in the composite gel sample used for chemical analysis. In powder immersion mounts it looked like alkali-silica gel. There were clear and brownish translucent fragments with the properties shown below:

Clear Fragments		Brownish Translucent Fragments	
Amorphous	Crystalline	Amorphous	Crystalline
$n > 1.45$	$n < 1.45$	$n \leq 1.45$	$n \leq 1.45$

It seems probable that this too may be a multiphase material.

35. The probable assignments of lines comprising the bulk of the X-ray pattern of each of the crystalline gel phases just discussed are tabulated below. The material in column 2 was found as a pure phase and mixed with the material in column 1. The materials in columns 1 and 2 were both found mixed with the material in column 3.

Interplanar Spacings, d, A		
Crystalline Phase in Gel from 1/4-in. Void	Tan Layered Material	Crystalline Phase from Composite Sample Used for Chemical Analysis
11.5	10.8	13.2
8.6	3.06	12.2
6.7	3.01	7.0
5.0	2.78	6.5
3.6	1.83	5.3
3.5		3.8

(Continued)

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Interplanar Spacings, d , A		
Crystalline Phase in Gel from 1/4-in. Void	Tan Layered Material	Crystalline Phase from Composite Sample Used Chemical Analysis
3.04?		2.93
2.9		2.73
2.7		
2.6		
2.5		
2.23		
1.74		

36. The presumed three phases were not successfully identified. The interplanar spacings of the tan layered material include three of the characteristic spacings of semiamorphous hydrous calcium silicates. No patterns for the other two phases were found in the ASTM powder diffraction file or other sources available here.

Soils

37. The mineralogical composition of each of the 11 soil samples is shown in table 4. Their composition does not suggest any reason to suspect the soil adjacent to the dry-dock walls of causing movement of the structure due to volume change of the soil.

Discussion of Results

38. The rather unusual environment of the dry dock with its unequal periods of wetting and drying of the concrete probably resulted in moving concentration fronts or local concentrations of alkali from the cement which together with other environmental factors caused the reaction to occur.

39. Not all of the concrete exhibited alkali-silica reaction. This may signify that two cements were used and reaction was confined to the concrete made with the one of higher alkali content, or it may be due to an undetermined environmental factor. It seems more probable that cements of different alkali contents were involved.

40. All of the preliminary visual and low-power microscopical examinations indicated that deleterious alkali-silica reaction had occurred

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in five of the eight cores. This was indicated by the cracked concrete and the presence of copious amounts of what appeared to be typical gel reaction product. However, more detailed examinations indicated that the coarse aggregate was not among the types known to be reactive and the gel appeared to be more crystalline than such gel characteristically is. Since the preliminary examinations, the bulk of the work accomplished was the investigation of the unusual features of the aggregate and the gel. It was believed that this information would help to decide if alkali-silica reaction had occurred.

41. The results given in WES Technical Memorandum No. 6-224, entitled "Investigation of Reactivity Between Alkalies in Portland Cement and Aggregates Proposed for Use on Santee-Cooper Project, Moncks Corner, S. C.," are discussed in Progress Report 2 (Appendix B). Technical Memorandum No. 6-224 is appended to this report as Appendix C.

Literature Cited

1. U. S. Army Engineer Waterways Experiment Station, CE, "Handbook for Concrete and Cement," Aug 1949 (with quarterly supplements), Vicksburg, Miss.

2. Charleston Naval Shipyard Drydock No. 2, Location Plan for Docking.

    (a) Drydock No. 2 Elevations, H 302-1085, 21 Sept 1962.

    (b) Plug Elevations, Charleston Plan No. 66456, Drawing No. H 302-1086, 30 Oct 1956.

    (c) Plug Distances for Drydock Inspection, Charleston Plan No. 66456, Drawing No. H 302-1087, 30 Oct 1956.

3. American Society for Testing and Materials, "Index (Inorganic) to the Powder Diffraction File," Special Technical Publication 48-N2, 1964, Philadelphia, Pa.

4. Mielenz, R. C., Greene, K. T., and Benton, E. J., "Chemical Test for Reactivity of Aggregates with Cement Alkalies; Chemical Processes in Cement-Aggregate Reaction," American Concrete Institute, Proceedings, Vol 44, Nov 1947, pp 193-221.

5. Mather, B., "Cracking of Concrete in the Tuscaloosa Lock," Proceedings, Highway Research Board, Vol 31, 1952, pp 218-233.

Correspondence and Records

Mr. R. C. Flanders of Fay, Spofford and Thorndike, Inc., provided the following correspondence and records which were consulted during the investigation:

Correspondence

Date	From	To
8 July 65	Dr. L. S. Brown	Mr. F. L. Lincoln
13 July 65	Mr. F. L. Lincoln	Director, SE Division, Budocks
12 Aug 65	Dr. L. S. Brown	Mr. F. L. Lincoln
26 Aug 65	Mr. F. L. Lincoln	Dr. L. S. Brown
3 Sept 65	Dr. L. S. Brown	Mr. F. L. Lincoln
19 Nov 65	Mr. H. G. Protze	Dr. L. S. Brown
3 Dec 65	Dr. L. S. Brown	Mr. H. G. Protze

Records

July 65	Relative condition of monoliths shown on print of dry-dock walls, L. S. Brown
6 Sept 62	Inspection Report of Dry Dock No. 2, D. K. Royer, LCDR, USNR
21 June 63	Inspection Report of Dry Dock No. 2, and observations relative to enlargement of Dry Dock No. 2, A. S. Lippack, LCDR, USNR
Mar 64	Preliminary Engineering Report FY 1965, Improvements to Dry Dock No. 2, Fay, Spofford & Thorndike
65	Two prints of drawing No. TC-11(b)/C-134, Dry Dock No. 2, Location of Concrete Core Borings
26 Aug 65	Sheets 1 and 2, Raymond Concrete Pile Division Test Boring Report (Holes 9 and 10)

Table 1

Lateral Movements, in Inches, of Dry Dock

| Location on Dock Scale ft** | As Measured at Edge of Top of Dry Dock,* 16 June 1953-12 June 1963 | | | | | |
| | North Wall | | | South Wall | | |
	16 June 1953	12 June 1963	Diff†	16 June 1953	12 June 1963	Diff†
454	0.50	0.56	+0.06	0.81	0.88	+0.07
436††	0.19	0.25	+0.06	0.50	0.62	+0.12
433	11.94	12.12	+0.18	0.06	0.19	+0.13
384††	0.12	0.25	+0.13	0.31	0.19	-0.12
382	0.62	0.56	-0.06	0.62	1.50	+0.88
388††	0.25	0.38	+0.13	0.06	0.19	+0.13
336	0.69	0.69	0.00	0.50	0.75	+0.25
292††	0.38	0.31	-0.07	0.19	0.25	+0.06
287	0.31	0.19	-0.12	0.19	0.19	0.00
236††	0.75	0.81	+0.06	0.87	0.94	+0.07
234	0.94	1.00	+0.06	0.62	0.50	-0.12
182††	0.94	1.00	+0.06	0.75	0.81	+0.06
180	0.25	0.25	0.00	0.62	1.00	+0.38
123††	0.19	0.25	+0.06	0.81	0.87	+0.06
121	0.12	0.62	+0.50	0.94	1.69	+0.75
28††	0.12	0.12	0.00	0.37	0.31	-0.06
26	5.69	6.56	+0.87	0.37	1.44	+1.07
A to B	0.50	0.69	(+0.19)	--	--	--
C to D	0.00	0.25	(+0.25)	--	--	--
Cumulative	--	--	+1.92	--	--	+3.73

| Location on Dock Scale, ft | As Measured from Plugs in Floor Near East and West Ends | | |
	16 June 1953	12 June 1953	Diff†
W end 454	0.19	2.50	+2.31
E end 0.0-2	0.19	0.94	+0.75

* See reference 2(c).
** The western plug of each pair is located with respect to the nearest point shown on the dock scale in reference 2(c).
† Plus sign (+) indicates elongation; minus sign (-) indicates contraction.
†† Pair located on opposite sides of a construction joint.

Table 2

Vertical Movements, in Feet, in and Adjoining Dry Dock

Date Measured	Plugs Adjoining North Wall			Plugs in North Wall			Plugs Adjoining South Wall			Plugs in South Wall		
	4	11	18	5	12	19	10	17	24	9	16	23
July 1945-April 1953												
7-11-45	0.475	0.458	0.638	0.612	0.613	0.601	0.448	0.467	0.501	0.570	0.615	0.595
4-22-53	0.478	0.461	0.640	0.701	0.651	0.661	0.437	0.462	0.506	0.632	0.620	0.631
Difference	+0.003	+0.003	+0.002	+0.089	+0.038	+0.060	-0.011	-0.005	+0.005	+0.062	+0.005	+0.036
April 1953-June 1963												
4-22-53	0.478	0.461	0.640	0.701	0.651	0.661	0.437	0.462	0.506	0.632	0.620	0.631
6-14-63	0.477	0.426	0.631	0.752	0.666	0.698	0.436*	0.452*	0.488	0.695	0.614	0.710
Difference	-0.001	-0.035	-0.009	+0.051	+0.015	+0.037	-0.001	-0.010	-0.018	+0.063	-0.006	+0.079
July 1945-June 1963												
Total difference	+0.002	-0.032	-0.007	+0.140	+0.053	+0.097	-0.012*	-0.015*	-0.013	+0.125	-0.001	+0.115

Note: Plugs adjoining the north and south walls of the dry dock are in fill. The fill subsided on both sides of the dry dock.

* Reading taken 3-26-57; plug subsequently destroyed.

Table 3

Chemical Analysis of Secondary Reaction
Product (Gel) in Concrete Cores

Composition	Percent	Moles per 100 g of Dried Sample
H_2O (loss at 450 C)	17.23	1.16
SiO_2	66.00	1.10
R_2O_3*	1.88	0.02
CaO	11.54	0.21
MgO	0.00	0.00
Na_2O	1.30	0.02
K_2O	19.00	0.20
Cl^-	0.39	Negligible
$SO_3^=$	Trace	Trace
Total	100.11	

Note: Underlined values are the major constituents used in calculating the
general formula in paragraph 33d.
* Assumed to be Al_2O_3; actually there is a trace of iron and perhaps
other elements present also.

Table 4

Mineralogical Composition of Soils Adjacent to Dry Dock No. 2

Based on X-Ray Diffraction Examination

Depth, ft	5	5	10	10	15	20	25	25	30	30	40
Boring 9 Sample No.	1	1	2	2	--	--	5	5	6	6	8
Boring 10 Sample No.	1	1	2	2	3	4	5	5	6	6	--
Field Description	Clayey Sand, or Silty Sand		Gray or Blue Clay		Brown Medium Sand	Marl	Marl		Marl		Marl
Boring No.	9	10	9	10	10	10	9	10	9	10	9
Clay mineral:											
Kaolinite	X	X	S	S	X	--	Tr	--	--	--	--
Mica	X	X	S	S	X	X	X	X	X	--	X
Montmorillonite type	X	?	S	S	S	--	X	--	--	--	--
Mixed layer (mica-chlorite or mica-vermiculite)	--	--	--	--	--	--	--	--	X	X	X
Carbonates:											
Calcite	--	--	--	--	--	X	X	X	S	S	S
Dolomite	--	--	--	--	--	S	X	X	S	X	X
Quartz	S	S	X	X	X	S	S	X	S	X	S
Feldspars	--	--	--	--	--	X	X	X	X	X	X
Gypsum	--	--	--	--	--	--	--	--	--	--	X

Note: S = major constituent; X = moderate or minor constituent; Tr = trace; -- = absent.
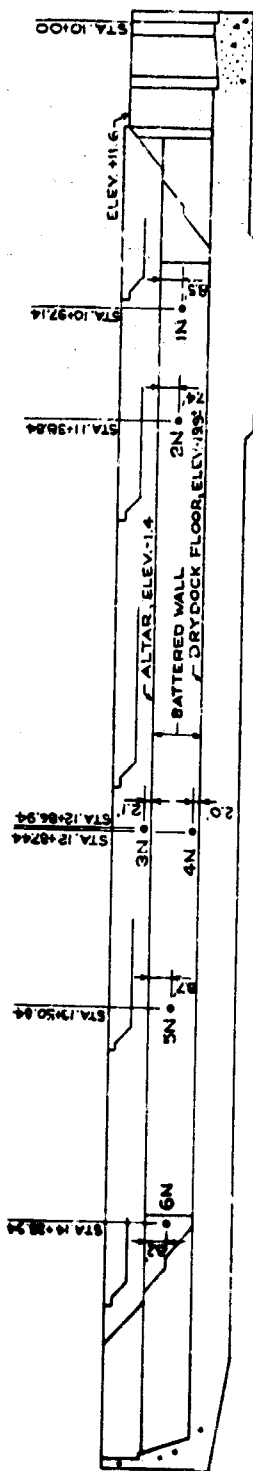
ELEVATION - NORTH WALL
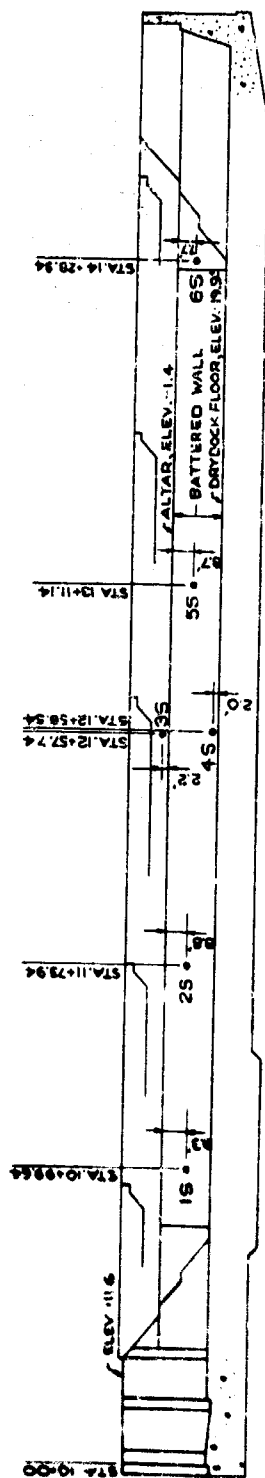
ELEVATION - SOUTH WALL
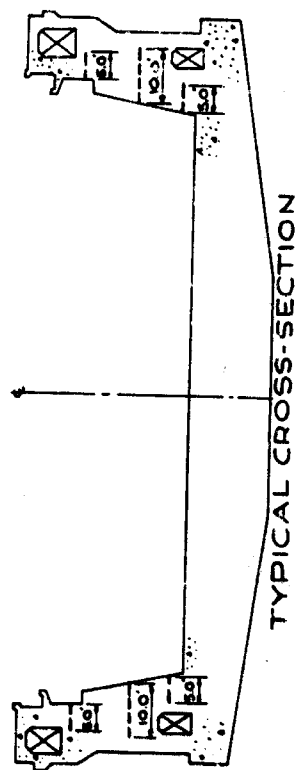
TYPICAL CROSS-SECTION

CONCRETE CORE BORINGS
ARE SHOWN THUS, 2N•

DEPARTMENT OF THE NAVY
SOUTHEAST DIVISION-BUREAU OF YARDS & DOCKS
U.S. NAVAL BASE   CHARLESTON, S.C.
CHARLESTON NAVAL SHIPYARD-CHARLESTON, S.C.

DRYDOCK NO.2

LOCATION OF CONCRETE
CORE BORINGS

NOV, 1965
FAY, SPOFFORD, & THORNDIKE, INC. BOSTON, MASS.
7C-11b
C-154

PLATE 1

APPENDIX A: CONCRETE CORES FROM DRY DOCK NO. 2, CHARLESTON, S. C.,
PROGRESS REPORT NO. 1, 14 JANUARY 1966

1. During a conference by telephone on 31 December 1965 among
Mr. H. G. Protze, Mr. R. C. Flanders, and Mr. Bryant Mather, it was agreed
that the work being done at the U. S. Army Engineer Waterways Experiment
Station (WES) on the subject cores would be briefly summarized and tentative
conclusions indicated in a progress report that would be completed on or
before 15 January 1966.

2. The information and samples made available by Messrs. Protze and
Flanders have been studied. The question that the investigation is in-
tended to answer--or assist in answering--concerns whether major portions,
specifically the north and south walls, of Dry Dock No. 2 should be incor-
porated in a modified and enlarged dry dock, or whether the present con-
dition and anticipated future condition of these walls are such as to indi-
cate that they should not be so incorporated. It is understood that a
conclusion favorable to their incorporation would permit a major savings
in cost of the contemplated modification and that their removal and re-
placement at the time of modification would add to the cost of the modifi-
cation to an extent that is not excessively greater than would be expected
to be incurred were such removal and replacement required at a later date.

3. Concrete cores taken from the walls have been examined. The
cores were taken by drilling horizontally from within the dry-dock chamber.
Some cores represented concrete that can, by inspection of the cores and
the portions of the structure from which they were taken, be seen to have
undergone rather severe cracking and deterioration; other cores represented
concrete that did not show such features.

4. Essentially all the aggregate that can be seen in and on the cores
is natural quartz sand and gravel having the appearance of that making up
similar deposits that occur frequently along the Atlantic Coast from Long
Island to Florida. Such aggregates have often been tested for reactivity
with alkalies but, so far as is known, no laboratory tests for reactivity
have suggested a degree of reaction such as to indicate a need for precau-
tions to be taken to avoid expansion of concrete. WES Technical

A1

Memorandum No. 6-224, October 1946, "Investigation of Reactivity Between Alkalies in Portland Cement and Aggregates Proposed for Use on Santee-Cooper Project, Moncks Corner, S. C.," included studies of two sources of sand and gravel: Becker County Sand and Gravel Co., Cheraw, S. C., and Lawrence Stone and Gravel Co., Hamlet, N. C. Mortar bars made with these materials indicated no significant expansion; parallel specimens made with known reactive aggregate showed severe expansion. Quartz is regarded as "nonreactive" or "innocuous" from the standpoint of reactivity with alkalies.

5. Samples of aggregate particles were cut with a small (0.35 in.) diamond core drill from cores from the dry dock representing both damaged (cracked) (cores 6N-1, 1S-6, 2S-4, and 6S-1) and undamaged concrete (cores 3S-3 and 4N-5). These aggregate cores were prepared and tested in accordance with ASTM Designation: C 289-65, "Standard Method of Test for Potential Reactivity of Aggregates (Chemical Method)" (also see CRD-C 128-62),[1]* except that only 30-35 g of material in the fraction passing the No. 50 and retained on the No. 100 sieves were available for testing. The results were:

Aggregate from Core No.	S_c	R_c
3S-3, 4N-5	31	0
6N-1, 1S-6, 2S-4, 6S-1	25	0

Fig. 2 of ASTM C 289 provides a basis for evaluating these results. Points plotted to the left of the line represent "innocuous aggregates." Point No. 66 on this figure represents quartz from near Denver, Colorado (see table 5, pp 202-203),[4] and has coordinates $S_c = 31$, $R_c = 31$ and is regarded as innocuous. The points representing the tests reported herein are not regarded as significantly different from point No. 66. The value of 0 for R_c is regarded with suspicion; if this value were in the range 10 to 20 it would be more reasonable, and were it in this range the interpretation would not be different. Possibly the low R_c indicates alkali in the aggregate particles not completely removed during preparation of the test samples.

---

* Raised numbers refer to similarly numbered items in the Literature Cited at the end of the main text of this report.

6. The study of the aggregate therefore indicates the following:

    a. By direct petrographic examination the aggregate is indicated to be essentially quartz.

    b. By the quick chemical test the aggregate is found to behave as quartz is expected to behave, and would be classed as innocuous.

    c. Similar aggregates previously examined petrographically and tested in mortar bars and for chemical reactivity have given similar indications of innocuousness.

7. The damaged concrete is clearly damaged. The evidence both from the concrete itself and from reports of examinations of the structure strongly suggests damage by cracking and crushing due to internal expansion of the sort induced by the alkali-silica reaction. Examination of the damaged concrete reveals an abundance of white reaction product superficially similar to that found in other structures that have shown cracking due to internal expansion produced in consequence of the alkali-silica-reaction (compare "Cracking of Concrete in the Tuscaloosa Lock" by Bryant Mather).[5] This material, upon X-ray diffraction study, differs from alkali-silica-reaction product previously studied in being better organized (more crystalline) and containing X-ray diffraction lines that have not yet been identified as belonging to substances for which patterns have been recorded.

8. The tentative hypothesis is that the reaction that has occurred is the alkali-silica reaction and that the cracking in the structure, insofar as it is a manifestation of the behavior of the concrete as a material, is wholly or predominantly due to the internal expansion that is a consequence of this reaction and the expansion of the reaction product. This hypothesis does not provide an explanation for the reactivity of the quartz aggregate which should not be reactive nor does it provide an explanation of the unusual degree of crystallinity of the reaction product. The existence of both of these anomalies may well have been contributed to by the environment of the structure, particularly the fact that it has been periodically filled with and emptied of sea water. Evidence of damage due to the characteristic attack of sulfates in sea water on aluminates in hydrated cement was noted, but to a materially smaller degree than was the evidence of reaction producing the product previously described. However, the role of

the ions in sea water in enhancing the solubility of silica, the presence
from the sea water environment of an essentially unlimited supply of sodium
ion, and the role of the sea water in chemically altering the alkali-silica-
reaction product are regarded as potentially significant and meriting fur-
ther investigation.

9. It is recalled that dry docks at both Brooklyn, New York, and
Norfolk, Virginia, presumably made using aggregates of a similar nature to
those in the Charleston Dry Dock, have manifested expansion and cracking.
In both cases the expansion presumably ceased or essentially ceased after
a time. It is believed possible that the abnormal nature of the reaction
product found in the concrete under study may have resulted from alteration
over a considerable period of exposure subsequent to its having been formed.
Data regarding recorded vertical and horizontal movements in the period
1953-1963 in the dry dock fail to indicate progressive expansion.

10. It is therefore concluded:

a. The damage that has taken place is due to the expansion of
   the concrete caused by expansion of the product of the re-
   action between alkalies and silica in the aggregates.

b. The aggregates are of a type not regarded as reactive with
   alkalies to an extent such as to cause expansion; but pos-
   sibly the environment is such as to render them reactive in
   this situation.

c. The indications are that the expansion that produced the
   cracking has ceased and the structure has become relatively
   dimensionally stable. Other dry docks on the Atlantic Coast
   appear to have manifested such behavior.

d. In the interests of economy it would appear proper to include
   the walls of the present structure in the modified structure.

e. In future construction of dry docks and modifications of dry
   docks along the Atlantic Coast, and particularly at Charles-
   ton, S. C., the allowable types of concrete aggregates should
   not include natural gravels composed primarily of quartz.
   The cement should be required to meet the provisions of ASTM
   or Federal Specifications for type II (low-alkali).

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APPENDIX B: CONCRETE CORES FROM DRY DOCK NO. 2,
CHARLESTON, S. C., PROGRESS REPORT NO. 2,
2 FEBRUARY 1966

1. During a telephone conservation between Mr. R. C. Flanders and Mr. Bryant Mather, it was agreed that a brief second progress report to supplement the progress report of 14 January 1966 would be prepared at the U. S. Army Engineer Waterways Experiment Station (WES) and transmitted before 4 February 1966.

2. A total of eight core sections have been received for study, as follows:

Field No.	Depth Back of Face, in.	Condition
1S-6	41-3/4 to 49	Cracked
2S-4	39-1/2 to 53-3/4	Cracked; reaction product
3S-3	28 to 38	No visible cracks or deposits
4S-4	48 to 52	No visible cracks or deposits
6S-1	0 to 12	Cracked; reaction product
4N-5	32-1/4 to 44-3/4	No visible cracks or deposits
6N-1	0 to 15	Cracked; reaction products
6N-3	27-1/4 to 39-1/2	Cracked; reaction products

All cores were taken from elevations -10.6 to -17.9, except 3N which was taken at an elevation of +0.7 and 3S which was taken at an elevation of +0.8. Unless core 3N shows evidence of reaction, the cores that show reaction represent the lower third only of the wall, so that there is no representation of reacted concrete in the upper two-thirds of the wall that has been examined here. The lateral distribution of the cores along each wall indicates reacted concrete in both walls near the inboard end (6N, 6S) and toward the outboard end (1S and 2S, and 2N which was examined by Dr. Brown) with regions of unaffected concrete midway on each side (4N, 4S, and 3S, and 5S which was examined by Dr. Brown).

3. Visual examination of all cores, and examination of thin sections of cores 4S-4, 6N-3, 1S-6, and 2S-4 did not furnish evidence to establish that more than one source of coarse aggregate is represented in these cores.

If two or several sources are represented, they were very similar in composition and history. Examination of the thin sections failed to reveal evidence that more than one source of cement is represented; discrimination between two cements in thin sections of concrete is sometimes but not usually possible.

4. A sample of the gel-like reaction product was handpicked from cores 1S-6, 2S-4, 6N-1, and 6S-1. A chemical analysis of the 0.4-g sample was made after drying the sample at 450 C. This ignition temperature was chosen because differential thermal analysis of the gel indicated loss of all the water by that temperature. The results are shown below, based on weight of dried material.

Determination	Weight Percent	Calculated Moles in 100 g of Dried Sample
H_2O (lost at 450 C)	17.23	1.16
SiO_2	66.00	1.10
R_2O_3*	1.88	0.02*
CaO	11.54	0.21
MgO	0.00	0.00
Na_2O	1.30	0.02
K_2O	19.00	0.20
Cl^-	0.39	Negligible
$SO_3^=$	Trace	Trace
Total	100.11	

* Assuming all R_2O_3 is alumina. A trace of iron, and possibly other elements, was present.

If the proportions of principal constituents are expressed based on 2 moles of K_2O, assuming loss at 450 C in water, they are:

$$2K_2O:2.10CaO:11SiO_2:11.6H_2O$$
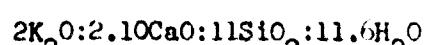
5. The composition of the reaction product establishes the hypothesis, tentatively accepted in the progress report of 14 January 1966, that the principal reaction that has damaged the concrete is alkali-silica reaction. The original assumption in the earlier progress report that the unlimited supply of sodium ion from sea water played a part in the reaction appears to be wrong, since the ratio of sodium to potassium in the reaction product is 1 to 16.4, and in sea water the ratio of sodium to potassium is 1 to 0.0358. The predominance of potassium over sodium in the reaction product suggests that the alkali was derived from the cement, since potassium is more abundant than sodium in most cements produced in this country.

6. The absence of magnesium, the low proportion of Al_2O_3 (R_2O_3 of the analysis), and the low amounts of chlorine and sulfate ion support the conclusion that normal sea-water attack on concrete is not the reaction that has taken place. The characteristic reaction products of sea-water attack are ettringite ($3CaO.Al_2O_3.3CaSO_4.31H_2O$), magnesium hydroxide ($Mg(OH)_2$), gypsum, and silica gel. The chemical analysis of the principal reaction product, microscopic examination of the concrete, and X-ray diffraction examination of cement paste concentrates all indicate relatively low amounts of ettringite, no gypsum, and no more magnesium hydroxide than would be expected from hydration of MgO from the cement clinker.

7. The damaged cores were oriented as they were orginally located in the structure, and general direction of elongation and inclination of the major crack planes were determined (fig. B1). If it is assumed that the concrete expanded toward the free side and consequently cracked normal to the available expansion direction, a crack pattern like the one shown would be produced. Only trends are shown in the figure; the extent in length or in depth in the wall of the crack system is not known.

8. Length-change measurements and changes in elevation have been analyzed. The lateral measurements cover the period June 1953 to June 1963. Considering the north wall, the length changes from the plug at 454 ft on the dock scale to the plug at approximately 121 ft on the scale total 0.55 in. (see table 1, main text). From the plug at approximately 121 ft through that at 26 ft, the movements total 1.37 in. On the south wall, from the plug at 454 ft to the plug at 121 ft, the movements total 1.97 in., and

B3
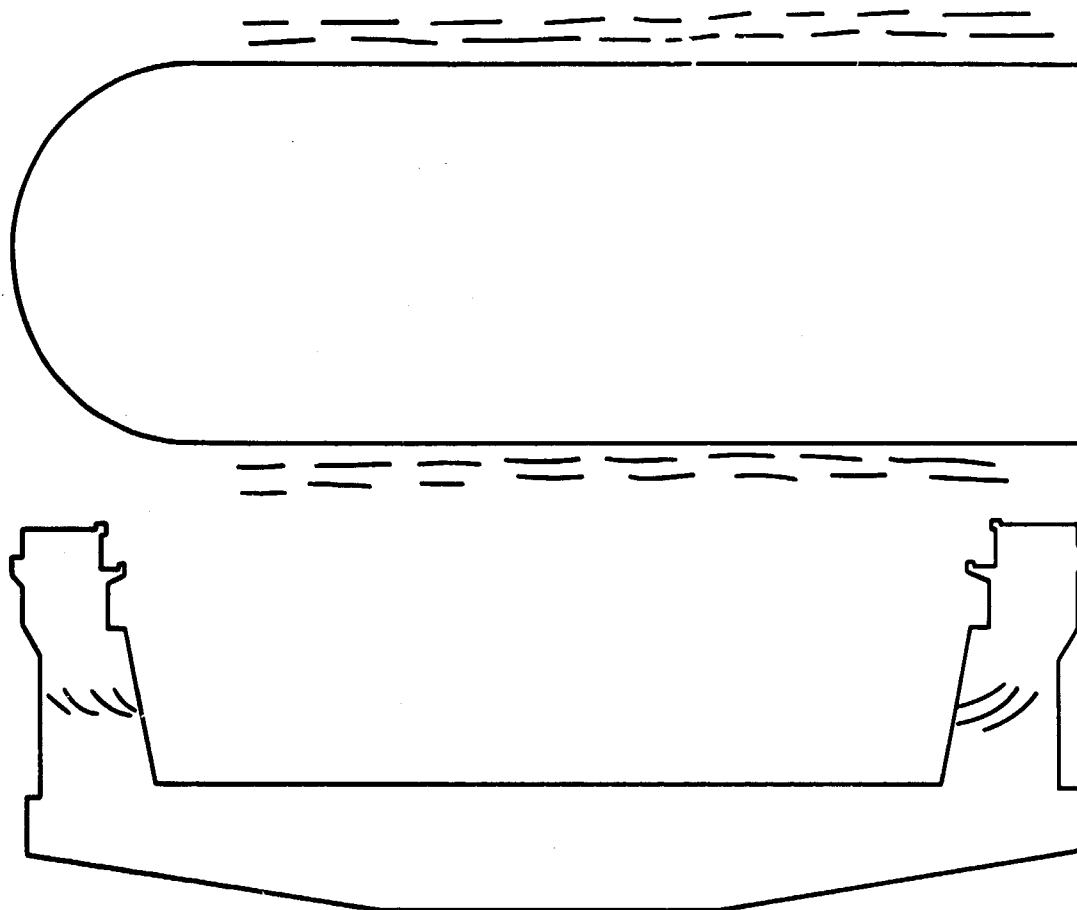
Fig. B1. Sketch plan and cross section, Dry Dock No. 2, showing directions of elongation and inclination of major crack systems in damaged cores. The sketch indicates only direction and inclination, not extent or distribution

from the plug at 121 ft through that at 26 ft, 1.76 in. On both walls, there is most movement in the outboard 100 ft. No clear trend in rate is discernible.

9. The relevant measurements of change in elevation concern three plugs on the north and three on the south wall, and cover the period 1945 to 1963. Changes in elevation were considered in two sets, from 11 July 1945 to 22 April 1953, and from 22 April 1953 to 14 June 1963. During the earlier, eight-year period, two of the three plugs in the north wall (plugs 5 and 19) moved 0.069 and 0.060 ft, respectively, but in the next ten years they moved 0.051 and 0.037 ft, respectively, showing a decreasing rate of movement. In the south wall, plugs 9 and 22 moved 0.062 and 0.076 ft,

respectively, during the first eight years; during the next ten years, the movements were 0.063 and 0.079 ft, respectively, showing a decrease in rate for plug 9 but an increase for 23. On both walls, the western and eastern ends rose more than the middle as far as the measurements show. Plug 23, toward the east end of the south wall (opposite 45 ft on the dock scale, drawing H 302-1086 on Charleston Plan No. 66456), has shown an increased rate of movement in the period 1953 to 1963 (see table B1).

    10.   Conclusions and recommendations of this report are:

        a. The composition of the reaction product establishes that alkali-silica reaction is the agent that has damaged the concrete.

        b. The source of the alkali for alkali-silica reaction must be assumed to be the cement, because the preponderance of potassium over sodium in the reaction product eliminates sea water as the source.

        c. We have no explanation of the fact that quartz, a material inert in alkali-silica reaction at normal laboratory temperatures, reacted in this case. Quartz is known to react with alkali at elevated temperatures. Research on the conditions that can develop alkali reactivity of quartz in conditions that exist in structures is needed.

        d. Plug 23 on the south wall (opposite 45 ft on the dock scale) has moved at an increased rate in the period 1953-1963 as compared to 1945-1953 (table B1). The total change in elevation is 0.115 ft. The rest of the data on rate of movement shows that changes in movement in the wall went on at a lower rate in 1953-1963 than in 1945-1953.

        e. It is recommended that the present elevation of the plugs along the north and south walls be checked to establish whether plug 23 is moving at an increased or a diminished rate since 1963.

        f. Cumulative lateral movements in the period 1953-1963 were 1.92 in. in the north wall and 3.73 in. in the south wall. East of 123 ft on the dock scale, the north wall elongated 1.37 in. and the south 1.76 in. On the south wall, an elongation of 0.88 in. at the plug opposite 382 ft on the dock scale and an elongation of 0.38 in. at the plug opposite 180 ft are the greatest values on either wall west of the 123-ft mark.

        g. It is recommended that the lateral measurements on the walls be checked to establish whether movement has slowed since 1963.

        h. The upper two-thirds of the wall are represented by only two

cores, 3S from elevation +0.8 and 3N from elevation +0.7. All the other cores represent elevations -10.6 to -17.9.

i. Unless inspection of the structure has established the condition of the upper two-thirds of each wall so that it can be adequately compared with that of the bottom third, it is recommended that vertical cores be taken near the eastern and western ends of each wall in the section it is desired to retain. The cores should be located between the upper tunnel and the dry-dock basin. When a wall or pier is affected by alkali-silica reaction, the upper, more lightly loaded part of the structure usually shows more advanced reaction than the lower. It would be undesirable to reach a conclusion about the utility of the wall based on samples that may represent the better rather than the average condition of the concrete.

j. Assuming the recommended measurements of changes in length and elevation confirm the general indication that expansion is slowing in most of the structure, it would appear proper in the interests of economy to include the existing walls in the modified structure.

k. In the modification and in future dry-dock construction along the Atlantic coast, allowable concrete aggregates should not include natural gravels composed primarily of quartz. The cement should be required to meet the provisions of ASTM or Federal Specifications for type II (low-alkali).

B6

Table B1

Changes in Elevation, Plug 23, 1945-1953

Date	Elevation ft	Change from Previous Reading, ft	Cumulative Change to Date, ft	Remarks
7-11-45	0.595	0.0	0.0	
10-30-45	0.605	+0.010	+0.010	
2-1-46	0.601	-0.004	+0.006	
5-10-46	0.603	+0.002	+0.008	
8-15-46	0.592	-0.011	-0.003	No significant changes during this period
1-2-47	0.594	+0.002	-0.001	
4-1-47	0.597	+0.003	+0.002	
10-1-47	0.599	+0.002	+0.004	
4-1-48	0.601	+0.002	+0.006	
4-1-49	0.598	-0.003	+0.003	
4-1-50	0.624	+0.026	+0.029	
4-30-51	0.621	-0.003	+0.026	
4-1-52	0.621	0.0	+0.026	
4-22-53	0.631	+0.010	+0.036	
4-26-54	0.641	+0.010	+0.046	At least three significant changes during this period
4-18-55	0.659	+0.018	+0.064	
4-5-56	0.668	+0.009	+0.073	
3-26-57	0.666	-0.002	+0.071	
10-1-62	0.710	+0.044*	+0.115	
6-14-63	0.710	0.0	+0.115	

* Change at an average rate of 0.0088 ft/yr.

APPENDIX C

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY

MISSISSIPPI RIVER COMMISSION

INVESTIGATION OF REACTIVITY BETWEEN ALKALIES

IN PORTLAND CEMENT AND AGGREGATES

PROPOSED FOR USE ON

SANTEE-COOPER PROJECT, MONCKS CORNER, S. C.

TECHNICAL MEMORANDUM NO. 6-224

U. S. WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

OCTOBER 1946

C1

CONTENTS

INVESTIGATION OF REACTIVITY BETWEEN ALKALIES

IN PORTLAND CEMENT AND AGGREGATES

PROPOSED FOR USE ON

SANTEE-COOPER PROJECT, MONCKS CORNER, S.C.

SYNOPSIS

1. An investigation of the potential reactivity between certain
aggregates and portland cements proposed for use in concrete construc-
tion on the Santee-Cooper Project was made at the request of the South
Carolina Public Service Authority. This investigation involved the
fabrication of sets of mortar bars containing nine different aggregates
combined with a cement of normal-alkali content and with a high-alkali
cement, and of control bars made with a standard reactive aggregate.
The bars were stored at 70°F in sealed cans over water for six months
and observations of length change were made.

2. The aggregates submitted for test did not show expansion
either with cements of normal- or high-alkali content. They are there-
fore regarded as non-reactive. When a control aggregate of known
reactivity was used with the cement of highest Na_2O content of those
submitted, severe expansion occurred, indicating that the cements with
high-alkali content were capable of producing deleterious reaction. The
cement of normal-alkali content did not react with the control reactive
aggregate to cause deleterious expansion.

INTRODUCTION

3. The investigation reported herein was requested by Mr. J. H. Moore, Chief Engineer, South Carolina Public Service Authority, Moncks Corner, S. C., in a letter dated 29 October 1945 to the Chief of Engineers. Reply to this letter was made by the Office, Chief of Engineers, under date of 6 November 1945 stating that the tests requested could be made by the Central Concrete Laboratory, Mt. Vernon, N. Y. (now the Concrete Research Division, U. S. Waterways Experiment Station). Further arrangements were made by correspondence between Mr. Moore and the Office, Chief of Engineers; the investigation was authorized in letter from the Office, Chief of Engineers, to the Division Engineer. North Atlantic Division, dated 5 January 1946.

4. The investigation was accomplished at the Central Concrete Laboratory, Mt. Vernon, N. Y., under the supervision of Mr. C. E. Wuerpel, Engineer-in-Charge. Mr. Wuerpel was assisted in the testing program by Messrs. Bryant Mather, William Walton, Chaja Weinbaum, Albert Weiner, and Alexander Brody, and by Mrs. Katharine Mather and Miss Rhoda Klein. This report was prepared by Mr. Bryant Mather.

PART I: PREPARATION OF MATERIALS AND TEST SPECIMENS

Materials Submitted for Test

Aggregates

5. Samples of nine aggregates were received in accordance with requests made to the producers by the South Carolina Public Service Authority. These aggregates consisted of two sands, two gravels and five crushed stones, as listed on table 1.

Cements

6. Samples of twelve cements were also received in accordance with requests made to the manufacturers by the South Carolina Public Service Authority. These cements are listed in table 2.

Control Materials

7. In addition to the aggregates and cements submitted for test, an aggregate of positive reactive nature was prepared in the laboratory by blending siliceous sand from Long Island, N.Y., with 3 per cent crushed opaline chert from California. A standard high-alkali cement was also selected from stocks at the laboratory for use as a control. It is listed on table 2 as cement no. 13.

Preparation of Materials

Aggregates

8. Each of the nine aggregates was prepared by crushing and pulverizing as required, and by sieving, to provide the required number

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of batches, each of the following weight and grading:

Sieve No.		Individual	Weight,
Passing	Retained on	Per Cent	grams
4	8	19	192.375
8	16	19	192.375
16	30	19	192.375
30	50	19	192.375
50	100	19	192.375
100	Pan	5	50.625
	Total	100	1012.500

9. The laboratory-made reactive aggregate was prepared to this same grading.

Cements

10. Each of the thirteen cements was subjected to chemical analysis for determination of per cent Na_2O, K_2O, and total water-soluble alkali. The results of these analyses are given in table 2. On the basis of these results cement no. 3 (Lehigh, Birmingham, Ala.) was selected for use in the major group of test specimens since its total alkali content, calculated as Na_2O, was most nearly 0.50 per cent and also most nearly equal to the average total alkali content of the twelve cements submitted.

11. The laboratory standard high-alkali cement, no. 13 with 0.04 per cent Na_2O, 1.18 per cent K_2O, and 0.82 per cent total alkali calculated as Na_2O, was used for the second group of specimens.

12. These two cements, plus cement no. 1, Lone Star, Norfolk, Va., which had the highest Na_2O content, 0.70 per cent, were used in the

third group of specimens made with the laboratory-prepared reactive aggregate.

13. All three of the cements used in making mortar test specimens were subjected to complete chemical analysis, the results of which are given in table 3.

Preparation of Specimens

14. A total of 135 specimens were made from 45 batches of mortar representing 21 different test conditions. The distribution of specimens was as follows:

Cement	Rounds	Aggregates	Bars Per Round	Total Bars
# 3	3	9	3	81
#13	1	9	3	27
# 1	3	1	3	9
# 3	3	1	3	9
#13	3	1	3	9
			Total:	135

15. Each mortar batch contained 1012.5 g of aggregate, graded as shown in par. 8 above; 450.0 g of the indicated cement; and 225.0 g of water. In the cases where three rounds were made to represent the same combination, each round was made on a different day.

16. Each specimen consisted of a 1- by 1- by 11-in. bar molded with its long axis horizontal and containing embedded reference points in each end with 10 in. effective gage length between the points. After molding, the specimens were stored in fog in their molds to an age of 44 $\pm$ 4 hr, after which they were stripped and their lengths were determined.

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PART II: LENGTH-CHANGE MEASUREMENTS

Storage

17. Immediately after the initial length had been determined, the bars were placed in metal cans for exposure. The exposure cans were stored in a constant-temperature room maintained at 70°± 2°F. The specimens were supported in each can in a vertical position, the lower end of each bar resting on the false bottom of the can. Each can was sealed and the air surrounding the specimens was maintained at a relative humidity of 100 per cent by partly filling the space below the false bottom of the can with fresh water. All of the specimens in any one can were made with the same cement.

Measurements

18. Measurements of length were made in the storage room by means of a dial-gage length comparator graduated in ten-thousandths of an inch. Exposure was continued and measurements made until the specimens reached an age of approximately six months.

19. The average values for length-change of each group of three bars and of the three rounds of similar bars at each age are given in table 4. The average values for each test condition are plotted in plates 1-3.

PART III: RESULTS AND CONCLUSIONS

Cement No. 3 With Test Aggregate

20. The bars representing the nine test aggregates and cement
no. 3 all showed slight expansion at the early ages, the maximum
expansion shown by any set being 0.008 per cent at 35 days. The early
expansion was followed by shrinkage in all cases, the maximum net
shrinkage by any one set being 0.029 per cent at the six-month age.
Length changes of this magnitude are regarded as negligible. These
aggregates may therefore be regarded as non-reactive with normal
cements such as no. 3.

High-Alkali Cement With Test Aggregate

21. The bars representing the nine test aggregates and the
standard high-alkali cement no. 13 all showed slight expansion at the
early ages, the maximum expansion shown by any one set being 0.004 per
cent at 28 days. This early expansion, it will be noted, is even
smaller than that shown by these aggregates with the normal cement no.3.
As in the group with the normal cement, the early expansion was followed
by a shrinkage, the maximum net shrinkage by any one set being 0.030
per cent at 168 days. On the basis of these data, the aggregates may be
regarded as non-reactive with high-alkali cements such as no. 13.

Reactive Aggregate Control Series

Cement no. 3 and reactive aggregate

22. The bars made with the normal cement no. 3 and the reactive

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opaline aggregate showed less length change, on the average, than any other test condition included in this series. The first round of bars in this series showed a slight net expansion throughout the test, fluctuating from a minimum of 0.004 per cent at 3 days and 56 days to a maximum of 0.013 per cent at 126 days and 0.009 per cent at 6 months. The second round was intermediate in behavior and the third round showed almost no expansion. The third-round bars showed a maximum shrinkage of 0.026 per cent at 63 days and 0.021 per cent at 6 months. On the basis of these negligible length changes, cements such as no. 3 may be regarded as potentially incapable of causing deleterious reaction even when used with reactive aggregates.

Cement no. 1 and reactive aggregate

23. The bars made with the relatively high-Na_2O cement no. 1 and the reactive aggregate showed progressive and marked expansion reaching a maximum of 0.611 per cent at 168 days when the test was discontinued. It appeared at that time that the potential expansion at greater ages would have been still greater. A length change of this magnitude is regarded as indicating severe deleterious reaction. Cement no. 1 may therefore be regarded as one which might be expected to participate in deleterious reactivity if used with a markedly reactive aggregate.

High-alkali cement and reactive aggregate

24. The control series of bars made with high-alkali cement (no. 13) and the reactive aggregate showed severe expansion indicating marked deleterious reaction. The average expansion of 1.125 per cent at

168 days is believed to be considerably less than that which would have been attained had the test been continued to later ages.

Conclusions

25. The results of this investigation indicate that:

    a. The aggregates submitted are apparently non-reactive with cements of either normal or high-alkali content.

    b. The cement from the group submitted which had an alkali content most nearly equal to that of the average for the group apparently will not cause deleterious reactivity when used with any of the aggregates submitted or with an aggregate of known reactivity.

    c. The cement from the group submitted which had the highest Na_2O content will, when used with an aggregate of known reactivity, cause deleterious expansion.

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TABLE 1

AGGREGATES SUBMITTED FOR TESTING

Sand

1. Becker County Sand and Gravel Company, Gretchen (Cheraw), South Carolina
2. Lawrence Stone and Gravel Company, Hamlet, North Carolina

Gravel

3. Becker County Sand and Gravel Company, Gretchen (Cheraw), South Carolina
4. Lawrence Stone and Gravel Company, Hamlet, North Carolina

Crushed Stone

5. Rion Crushed Stone Company, Rion, South Carolina (granite)
6. Palmetto Quarries, Columbia, South Carolina (granite)
7. Blair Quarries, Columbia, South Carolina (granite)
8. Weston and Brooker, Columbia (Cayce), South Carolina (granite)
9. New York Trap Rock Company, Clinton Point, New York (dolomite)

TABLE 2

PORTLAND CEMENTS TESTED

Santee-Cooper Number	Cement	Na$_2$O %	K$_2$O	K$_2$O calc as Na$_2$O	Total Na$_2$+K$_2$O as Na$_2$O	H$_2$O -sol. Na$_2$O+ K$_2$O as Na$_2$O
13	RC-130 Alpha, Birmingham, Ala.	0.04	1.18	0.73	0.82	0.69
1	RC-131 Lone Star, Norfolk, Virginia	0.70	0.11	0.07	0.77	0.08
2	RC-132 Lone Star, Birmingham, Ala.	0.21	0.94	0.62	0.83	0.47
3	RC-133 Lehigh, Birmingham, Ala.	0.08	0.67	0.44	0.52	0.19
4	RC-134 Lehigh, Fordwick, Virginia	0.06	0.81	0.53	0.59	0.51
5	RC-135 Penn-Dixie, Clinchfield, Ga.	0.02	0.18	0.12	0.14	0.01
6	RC-136 Penn-Dixie Richard City,Tenn.	0.08	0.45	0.30	0.38	0.27
7	RC-137 Penn-Dixie, Kingsport, Tenn.	0.09	0.35	0.23	0.32	0.09
8	RC-138 National, Ragland, Alabama	0.07	0.18	0.12	0.19	0.03
9	RC-139 Alpha, Birmingham, Alabama	0.05	1.07	0.71	0.76	0.36

(Concluded on next page)

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TABLE 2 (Cont'd)

Santee-Cooper Number	Cement	Na_2O %	K_2O	K_2O calc as Na_2O	Total Na_2+K_2O as Na_2O	H_2O -sol. Na_2O+K_2O as Na_2O
10	RC-140 Universal Atlas, Birmingham, Ala.	0.09	0.67	0.44	0.53	0.14
11	RC-141 Southern States, Rockmart, Georgia	0.07	0.42	0.28	0.35	0.14
12	RC-142 Volunteer, Knoxville, Tenn.	0.04	0.47	0.31	0.35	0.11

The Lehigh, Birmingham, Alabama (RC-133) cement most closely approximates 0.50 per cent total alkali content, calculated as Na_2O.

TABLE 3

COMPLETE CHEMICAL ANALYSIS OF CEMENTS USED IN TESTS

	No. 13 Alpha, Birmingham RC 138 Per Cent	No. 1 Lone Star, Norfolk, Va. RC 131 Per Cent	No. 3 Lehigh, Birmingham RC 133 Per Cent
SiO_2	20.76	21.85	22.25
Al_2O_3	5.43	3.93	4.38
Fe_2O_3	2.53	4.91	3.62
CaO	61.75	63.88	62.81
MgO	2.92	1.01	3.02
SO_3	1.63	1.46	1.53
Ignition Loss	3.36	1.10	0.99
Total	98.38	98.14	98.60
Insoluble Residue	0.10	0.11	0.16
P_2O_5	0.087	0.230	0.070
Mn_2O_3	0.040	0.058	0.046
Na_2O	0.04	0.70	0.08
K_2O	1.18	0.11	0.67
H_2O Soluble Na_2O	0.05	0.06	0.02
H_2O Soluble K_2O	0.80	0.03	0.22
Free CaO	0.73	0.78	0.04

Compounds

C_3S	48.79	56.34	47.57
C_2S	22.79	20.23	27.99
C_3A	10.11	2.12	5.49
C_4AF	7.69	14.93	11.00
$CaSO_4$	2.77	2.48	2.60
CaO Saturation	65.87	68.94	69.72

Ratios

Colony's Ratio	2.66	2.63	2.56
Al_2O_3/Fe_2O_3	2.15	0.80	1.21
SiO_2/R_2O_3	2.58	2.39	2.76
CaO/SiO_2	2.97	2.92	2.82

TABLE 4

LENGTH CHANGES OF TEST SPECIMEN GROUPS

Length Change, in Ten-Thousandths of an Inch, at the Ages Shown Below

Set No.										Age in Days											
	2	3	5	7	14	21	28	35	42	49	56	63	70	77	84	98	112	126	140	168	182
3 A-1	0	+5	+5	+4	+5	+3	+4	+6	+6	+4	+1	-1	-3	-4	-5	-9	-8	-9	-9	-11	-10
B-1	0	+2	+3	+4	+2	+5	+2	+2	-2	-7	-9	-12	-15	-16	-18	-20	-16	-18	-15	-14	-15
C-1	0	+2	+3	+4	+4	+2	-3	-7	-8	-12	-13	-15	-19	-20	-20	-17	-19	-17	-23	-20	-23
Avg.	0	+3	+4	+4	+4	+3	+1	0	-1	-5	-7	-9	-12	-13	-15	-15	-14	-15	-16	-15	-16
3 A-3	0	+5	+5	+5	+3	+4	+4	+6	+6	+4	+2	0	-2	-4	-6	-9	-9	-9	-9	-12	-13
B-3	0	+5	+6	+5	+3	+3	+1	0	-5	-7	-10	-13	-15	-18	-19	-20	-16	-18	-15	-17	-17
C-3	0	+2	+3	+3	+2	0	-3	-6	-7	-11	-13	-15	-18	-19	-18	-15	-17	-18	-22	-19	-23
Avg.	0	+4	+5	+4	+3	+2	+1	0	-2	-5	-7	-9	-12	-14	-14	-15	-14	-15	-15	-16	-18

(a) Each set as originally prepared contained 3 bars. Unless otherwise noted, each value shown for a set of bars is an average of 3 readings.

Notes:

Cement: Lehigh 0.52% Na_2O

Aggregates:
1. Becker County Sand and Gravel Co., Cheraw, S. C. - Sand
3. Lawrence Stone and Gravel Co., Hamlet, N. C. - Sand

(Continued on next page)

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TABLE 4 (Continued)

Length Change, in Ten-Thousandths of an Inch, at the Ages Shown Below

Set No.(a)	Age in Days																				
	2	3	5	7	14	21	28	35	42	49	56	63	70	77	84	98	112	126	140	168	182
3(a) A-4	0	+5	+5	+5	+4	+4	+5	+8	+7	+5	+3	+1	-1	-3	-6	-9	-9	-9	-8	-15	-10
B-4	0	+4	+4	+5	+3	+4	+2	0	-5	-7	-10	-14	-17	-18	-20	-22	-18	-18	-16	-18	-19
C-4	0	+2	+3	+4	+3	+2	-2	-6	-6	-11	-13	-15	-18	-20	-20	-16	-19	-18	-19	-19	-21
Avg.	0	+4	+4	+5	+3	+3	+2	+1	-1	-4	-7	-9	-12	-14	-15	-16	-15	-15	-14	-17	-17
3(b) A-5	0	+5	+4	+4	+3	+1	+2	+4	+4	+2	0	-2	-4	-6	-9	-12	-11	-12	-11	-13	-13
E-5	0	+4	+4	+6	+3	+3	+1	0	-3	-7	-11	-14	-16	-18	-19	-21	-17	-17	-18	-18	-20
C-5	0	+3	+4	+5	+2	+1	-2	-5	-6	-11	-14	-16	-19	-21	-20	-17	-20	-20	-20	-21	-26
D-5	0	+4	+7	+8	+4	+1	-4	-7	-10	-13	-15	-18	-19	-19	-19	-17	-15	-17	-16	-20	
Avg.	0	+4	+6	+6	+3	+2	-1	-2	-4	-7	-10	-12	-14	-16	-17	-17	-16	-17	-16	-18	-20

(a) Each set as originally prepared contained 3 bars. Unless otherwise noted, each value shown for a set of bars is an average of 3 readings.

(b) Value shown is average of 2 bars.

Notes: Cement: Lehigh 0.52% Na₂O

Aggregates:
4. Becker County Sand and Gravel Co., Cheraw, S. C. - Gravel
5. Lawrence Stone and Gravel Co., Hamlet, N. C. - Gravel

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TABLE 4 (Continued)

Length Change, in Ten-Thousandths of an Inch, at the Ages Shown Below

Set No.(a)	Age in Days																				
	2	3	6	7	14	21	28	35	42	49	56	63	70	77	84	98	112	126	140	168	192
3 A-6 (b)	0	+5	+5	+4	+4	+2	+3	+6	+6	+4	+1	0	-2	-4	-6	-9	-9	-10	-9	-11	-10
B-6	0	+4	+4	+5	+2	+1	+1	-1	-6	-9	-13	-16	-17	-20	-21	-22	-18	-18	-20	-19	-20
C-6	0	+2	+3	+4	+2	+1	-3	-6	-8	-11	-13	-15	-18	-21	-20	-19	-20	-19	-21	-22	-24
D-6	0	+4	+8	+8	+6	+4	-1	-4	-7	-10	-12	-14	-16	-15	-15	-13	-12	-14	-13	-15	
Avg.	0	+4	+7	+7	+3	+2	0	-1	-4	-7	-9	-11	-13	-15	-15	-16	-15	-15	-16	-17	-18
3 A-7 (c)	0	+5	+4	+4	+4	+4	+5	+8	+6	+4	+3	+1	-3	-8	-9	-9	-9	-10	-8	-8	-10
B-7	0	+4	+4	+6	+3	+3	+2	+2	-1	-5	-8	-11	-13	-15	-16	-18	-15	-16	-17	-16	-17
C-7	0	+2	+3	+4	+2	+2	-3	-7	-9	-12	-14	-15	-19	-21	-20	-18	-18	-19	-20	-21	-24
D-7	0	+3	+3	+4	+5	+5	+4	+4	+3	0	-2	-4	-5	-6	-7	-8	-7	-6	-8	-9	
Avg.	0	+3	+3	+4	+3	+3	+2	+2	0	-3	-5	-7	-10	-12	-13	-13	-12	-13	-13	-13	-17

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(a) Each set as originally prepared contained 3 bars. Unless otherwise noted, each value shown for a set of bars is an average of 3 readings.

(b) Value shown is average of 2 bars.

(c) Value shown represents measurement of 1 bar.

Notes: Cement: Lehigh 0.52% Na_2O

Aggregates: 6. Rion Crushed Stone Company - Crushed Stone

7. Palmetto Quarries, Columbia, S. C. - Crushed granite

TABLE 4 (Continued)

Length Change, in Ten-Thousandths of an Inch, at the Ages Shown Below

Set No.(a)	Age in Days																				
	2	3	5	7	14	21	28	35	42	49	56	63	70	77	84	98	112	126	140	168	182
3 A-8	0	+4	+5	+5	+4	+3	+6	+8	+6	+5	+4	+3	0	-3	-7	-8	-9	-10	-9	-11	-10
(b)B-8	0	+3	+4	+5	+3	+6	+5	+2	-3	-7	-10	-13	-15	-18	-20	-22	-17	-17	-17	-16	-20
C-8	0	+1	+3	+3	-1	+1	-3	-7	-8	-11	-13	-15	-17	-20	-21	-19	-21	-20	-24	-22	-24
D-8	0	+3	+4	+5	+4	+6	+5	+5	+2	-1	-3	-5	-7	-6	-7	-9	-10	-7	-12	-13	
Avg.	0	+3	+4	+5	+2	+4	+3	+2	-1	-3	-5	-7	-10	-12	-14	-14	-14	-14	-16	-16	-18
3 A-9	0	+4	+4	+4	+4	+4	+6	+8	+7	+4	+2	0	-2	-5	-7	-8	-9	-10	-11	-11	-10
B-9	0	+3	+4	+4	+1	+3	0	-3	-7	-10	-13	-17	-19	-22	-23	-24	-21	-20	-22	-21	-23
C-9	0	+2	+4	+5	+2	+3	-4	-8	-9	-12	-14	-16	-19	-21	-21	-19	-20	-20	-25	-22	-25
Avg.	0	+3	+4	+4	+2	+3	+1	-1	-2	-6	-8	-11	-13	-16	-17	-17	-17	-17	-23	-18	-19
3L-10	0	+4	+3	+2	+3	0	+4	+4	+2	0	-2	-4	-7	-9	-12	-13	-15	-16	-16	-19	-18
F-10	0	+4	+4	+4	+3	+5	+1	-1	-7	-10	-13	-16	-19	-21	-23	-24	-22	-21	-22	-22	-23
C-10	0	+1	+1	+1	-3	.0	-6	-11	-13	-17	-19	-21	-23	-26	-26	-24	-26	-26	-28	-27	-29
Avg.	0	+3	+2	+2	+1	+2	0	-4	-6	-9	-11	-14	-16	-19	-20	-20	-21	-21	-22	-23	-23

(a) Each set as originally prepared contained 3 bars. Unless otherwise noted, each value shown for a set of bars is an average of 3 readings.

(b) Value shown is average of 2 bars.

Notes: Cement: Lehigh. 0.52% Na_2O

Aggregates: 8. Blair Quarries, Blair, S. C. - Crushed granite
9. Weston and Brooker Cayce, S. C. - Crushed granite
10. New York Trap Rock Co., Clinton Point, N. Y. - Dolomite sand

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TABLE 4 (Continued)

Length Change, in Ten-Thousandths of an Inch, at the Ages Shown Below

Set No.(a)	2	3	5	7	14	21	28	35	42	49	56	63	70	77	84	98	112	126	140	168	182
										Age in Days											
13 A-1	0	+1	+1	+2	0	+1	+2	-2	-4	-5	-8	-12	-14	-16	-18	-21	-20	-18	-16	-17	-17
" A-3	0	+2	+2	+2	-2	-1	0	-3	-4	-6	-9	-12	-14	-17	-19	-21	-20	-18	-16	-17	-20
" A-4	0	+3	+4	+4	+1	+2	+4	-1	-1	-3	-6	-10	-12	-16	-15	-18	-18	-16	-13	-13	-17
" A-5	0	+3	+3	+2	-3	-2	-2	-7	-7	-9	-13	-17	-19	-22	-22	-25	-25	-23	-21	-22	-22
" A-5	0	+2	+2	+2	-1	+2	+2	-2	-1	-4	-7	-12	-13	-16	-17	-19	-18	-17	-16	-15	-16
" A-7	0	+2	+1	0	-3	-1	+2	-3	-3	-5	-9	-13	-14	-18	-19	-22	-22	-20	-19	-16	-18
" A-8	0	+2	+1	0	-6	-4	-4	-8	-8	-10	-12	-17	-19	-22	-23	-25	-25	-23	-22	-21	-21
" A-9	0	+2	+2	+2	0	+3	+4	+1	-1	-4	-6	-10	-12	-14	-17	-19	-18	-16	-16	-16	-14
" A-10	0	+3	+1	-1	-7	-6	-5	-10	-10	-13	-16	-20	-22	-25	-27	-30	-30	-28	-27	-30	-27

(a) Each set as originally prepared contained 3 bars. Unless otherwise noted, each value shown for a set of bars is an average of 3 readings.

Notes: Cement: Alpha, 0.82% Na$_2$O

Aggregates:
A-1: Sand — Becker County Sand and Gravel Co., Cheraw, S. C.
A-3: Sand — Lawrence Stone and Gravel Co., Hamlet, N. C.
A-4: Gravel — Becker County Sand and Gravel Co., Cheraw, S. C.
A-5: Gravel — Lawrence Stone and Gravel Co., Hamlet, N. C.
A-6: Crushed Stone — Rion Crushed Stone Co.
A-7: Crushed Granite — Palmetto Quarries, Columbia, S. C.
A-8: Crushed Granite — Blair Quarries, Blair, S. C.
A-9: Crushed Granite — Weston and Brooker, Cayce, S. C.
A-10: Dolomite Sand — New York Trap Rock Co., Clinton Point, N. Y.
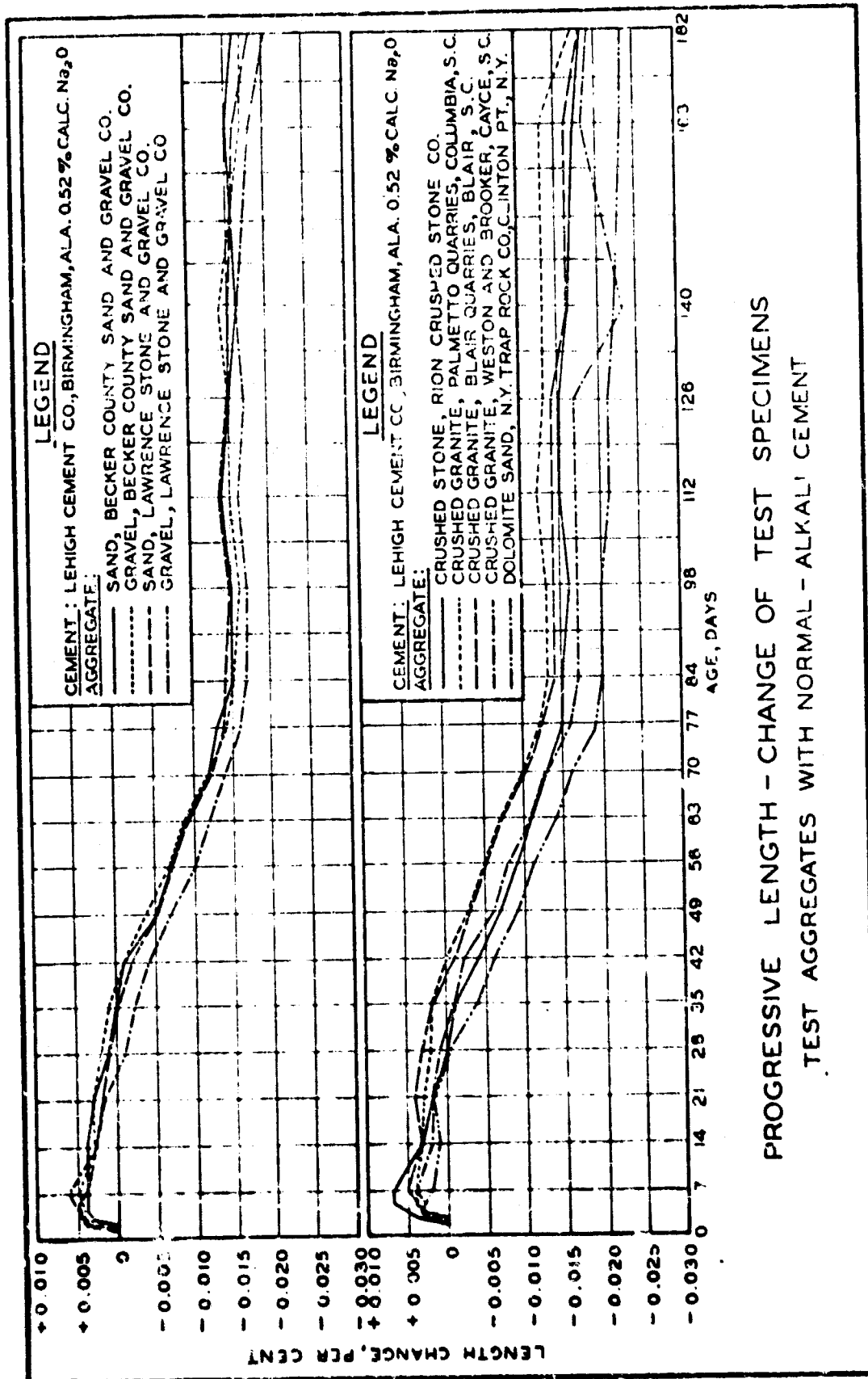
(Concluded on next page)

TABLE 4 (Continued)

Length Change, in Ten-Thousandths of an Inch, at the Ages Shown Below

Set No.(a)	Age in Days																				
	2	3	5	7	14	21	28	35	42	49	56	63	70	77	84	98	112	126	140	168	182
SC-1-A	0	+4	+3	+3	+3	+4	+5	+6	+14	+24	+57	+129	+236	+316	+376	+461	+493	+609	+659	+749	
B	0	+1	+1	+2	+3	+3	+3	+3	+7	+14	+28	+57	+129	+208	+279	+364	+429	+501	+541	+606	
(b)C	0	+2	0	-2	-2	-2	-2	+3	+5	+6	+11	+24	+58	+122	+173	+249	+255	+306	+430	+479	
Avg.	0	+2	+1	+1	+1	+2	+2	+4	+9	+15	+32	+70	+141	+215	+276	+358	+392	+472	+543	+611	
SC-3-A	0	+4	+4	+5	+5	+7	+9	+10	+8	+5	+4	+6	+5	+5	+5	+5	+7	+13	+12	+9	
B	0	+3	+6	+5	+1	-1	-6	-8	-12	-14	-15	-17	-19	-18	-18	-14	-11	-10	-12	-10	
C	0	+1	+1	0	-9	-12	-14	-18	-20	-20	-23	-26	-24	-22	-20	-21	-21	-23	-23	-21	
Avg.	0	+3	+4	+3	-1	-2	-4	-5	-8	-10	-11	-12	-13	-12	-11	-10	-8	-7	-8	-7	
SC-13-A	0	+2	+1	+1	+13	+320	+552	+669	+787	+864	+919	+1005	+1053	+1085	+1120	+1189		+1204	+1223	+1289	
B	0	+2	+4	+6	+25	+345	+463	+581	+650	+667	+690	+753	+812	+827	+838	+875	+888	+923	+949	+1019	
C	0	+2	+2	+1	+10	+237	+419	+555	+661	+728	+800	+850	+892	+917	+949	+970		+999	+1010	+1067	
Avg.	0	+2	+2	+3	+16	+301	+478	+602	+699	+753	+803	+869	+919	+943	+969	+999	+1025	+1042	+1061	+1125	

(a) Each set as originally prepared contained 3 bars. Unless otherwise noted, each value shown for a set of bars is an average of 3 readings.

(b) Value shown is average of 2 bars.

Notes: Cement: 1 = Lone Star, 0.77% Na$_2$O
            5 = Lehigh, 0.52% Na$_2$O
        13 = Alpha, 0.82% Na$_2$O

Aggregate: Long Island Sand + 3% Opaline Chert

C21

LEGEND

CEMENT : LEHIGH CEMENT CO., BIRMINGHAM, ALA. 0.52% CALC. Na₂O
AGGREGATE:

SAND, BECKER COUNTY SAND AND GRAVEL CO.
GRAVEL, BECKER COUNTY SAND AND GRAVEL CO.
SAND, LAWRENCE STONE AND GRAVEL CO.
GRAVEL, LAWRENCE STONE AND GRAVEL CO

LEGEND

CEMENT: LEHIGH CEMENT CO, BIRMINGHAM, ALA. 0.52 % CALC. Na₂O
AGGREGATE:

CRUSHED STONE, RION CRUSHED STONE CO.
CRUSHED GRANITE, PALMETTO QUARRIES, COLUMBIA, S.C.
CRUSHED GRANITE, BLAIR QUARRIES, BLAIR, S.C.
CRUSHED GRANITE, WESTON AND BROOKER, CAYCE, S.C.
DOLOMITE SAND, N.Y. TRAP ROCK CO., CLINTON PT., N.Y.

PROGRESSIVE LENGTH – CHANGE OF TEST SPECIMENS
TEST AGGREGATES WITH NORMAL – ALKALI CEMENT

LENGTH CHANGE, PER CENT

AGE, DAYS

PLATE 1

C.2

PLATE 2

C23

PROGRESSIVE LENGTH - CHANGE OF TEST SPECIMENS

TEST AGGREGATES WITH HIGH - ALKALI CEMENT

LEGEND

CEMENT: ALPHA, BIRMINGHAM, ALA. 0.82 % CALC. Na₂O
AGGREGATE:
SAND, BECKER COUNTY SAND AND GRAVEL CO.
GRAVEL, BECKER COUNTY SAND AND GRAVEL CO.
SAND, LAWRENCE STONE AND GRAVEL CO.
GRAVEL, LAWRENCE STONE AND GRAVEL CO.

LEGEND

CEMENT: ALPHA, BIRMINGHAM, ALA. 0.82 % CALC. Na₂O
AGGREGATE:
CRUSHED STONE, RION CRUSHED STONE CO.
CRUSHED GRANITE, PALMETTO QUARRIES, COLUMBIA, S.C.
CRUSHED GRANITE, BLAIR QUARRIES, BLAIR, S.C.
CRUSHED GRANITE, WESTON AND BROCKER, CAYCE, S.C.
DOLOMITE SAND, N.Y. TRAP ROCK CO., CLINTON PT, N.Y.

AGE, DAYS

LENGTH CHANGE, PER CENT

PROGRESSIVE LENGTH – CHANGE OF TEST SPECIMENS
REACTIVE AGGREGATE WITH NORMAL – AND HIGH–ALKALI CEMENTS

31867

C2l.

PLATE 3

DOCUMENT CONTROL DATA - R & D

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	2b. GROUP

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CONCRETE CORES FROM DRY DOCK NO. 2, CHARLESTON NAVAL SHIPYARD, S. C.

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final report

5. AUTHOR(S) (First name, middle initial, last name)

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Katharine Mather

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Southeast Division Bureau of Yards and Docks U. S. Navy

13. ABSTRACT

Eight concrete cores from Dry Dock No. 2, Charleston Naval Shipyard, were examined to determine if alkali-silica reaction had occurred in the concrete and whether, if this reaction had occurred, it was continuing. Some of the concrete and of the associated white porcelaneous secondary reaction product (gel) indicated alkali-silica reaction had occurred. However, the quartz aggregate used in the concrete is not among types of material usually considered to be reactive. Also, the gel was definitely more crystalline than alkali-silica gel has usually been found to be. None of the tests and examinations made of the gel, aggregate, cement paste, and concrete suggested that the aggregate would be diagnosed as reactive by normal criteria. Apparently, only one source of aggregate had been used. Chemical analysis of a 0.4-g sample of gel from the reacted concrete showed it to consist of water, silica (SiO_2), lime (CaO), and potassa (K_2O); the last amounted to 19%. The approximate formula of this material, $CaO \cdot K_2O \cdot 5SiO \cdot 5H_2O$, is reasonable as a generalized formula for impure alkali-silica gel; the microscopical examinations showed that the gel consisted of at least three crystalline phases. One included amorphous material that is probably alkali-silica gel. It is concluded that alkali-silica reaction had occurred and that the effects of this reaction have essentially terminated. Since the alkali portion of the gel was high in K_2O and low in Na_2O, it is believed that the source of the alkali was the cement rather than the sea water to which the concrete was exposed. The environment of the dry dock with its unequal periods of wetting and drying probably resulted in moving concentration fronts or local concentrations of alkali from the cement which together with other environmental factors caused the reaction to occur. Not all of the concrete exhibited alkali-silica reaction; this may signify that two cements were used and reaction was confined to the concrete made with the one of higher alkali content, or it may be due to an undetermined environmental factor. It seems more probable that cements of different alkali contents were involved. Progress reports 1 and 2 are included as Appendixes A and B, respectively, and U. S. Army Engineer Waterways Experiment Station TM 6-224 as Appendix C.

DD FORM **1473** REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

| 14. | LINK A | | LINK B | | LINK C | |
KEY WORDS	ROLE	WT	ROLE	WT	ROLE	WT
Alkali-aggregate reactions						
Charleston Naval Shipyard, S. C.						
Concrete cores						
Concrete testing						
Dry docks						